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**The psychology of vehicle performance:
implications for the uptake of electric vehicles**

by

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Submitted for the degree of Doctor of Philosophy, The Open University

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Affiliated Research Centre: Transport Research Laboratory

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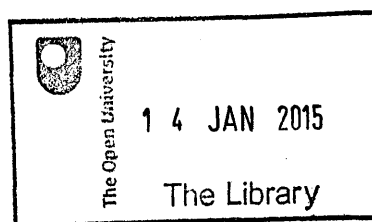
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Abstract

Road transport accounts for around 16% of global CO₂ emissions, and electric vehicles (EVs) represent a potential mitigation route. High performance might offset the disadvantages of higher cost and short range that make their uptake problematic. This research investigated how consumer drivers construe, perceive and value vehicle performance.

Research with UK drivers, using the repertory grid method, found that drivers construe vehicle performance as having two independent dimensions, dynamic and cruising performance.

A new inter-goal dynamics and feedback control model of driving behaviour was developed to account for differences in the opportunities afforded to perceive vehicle performance in naturalistic driving. This was embedded in a Bayesian model for perception of available vehicle performance. Driving simulation and test track experiments with UK drivers found that: driving behaviour was strongly affected by goal activation; drivers could perceive performance differences in naturalistic driving, but only if they were large; the lowest perceptual difference threshold, for mid-range available vehicle acceleration, was 7.7%; smaller differences could affect driving behaviour (overtaking) through a process of implicit learning.

The symbolic value of products is conferred by their symbolic meanings. Two new methods were developed to quantify symbolic meanings, grounded in costly signalling theory, which represents them in terms of personality traits of a typical user. The symbolic meanings of car types, performance attributes and driving styles were all measured.

In a randomised controlled trial, UK consumer drivers rated an EV better on dynamic and cruising performance than a conventional ICE control, but this benefit was insufficient to outweigh the disadvantages. The symbolic meaning of an EV was found to be consistent with cruising performance, but inconsistent with dynamic performance.

Extended-range EVs would have the dynamic and cruising performance benefits of EVs without the range disadvantages, and may be a desirable option for many once costs reduce.

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Chapter One. Abatement of carbon dioxide emissions from road transport

The need to reduce road transport CO₂ emissions

Global anthropogenic carbon dioxide emissions are thought to be causing rises in global average temperatures, with potentially damaging impacts on climate at both global and local levels (Allen et al., 2009; Matthews, Gillet, Stott, & Zickfeld, 2009; Meinshausen et al., 2009; Stern, 2007). The Intergovernmental Panel on Climate Change summarized the evidence in its fourth assessment report (Pachauri & Reisinger, 2007).

Transport accounts for some 23% of current global energy-related carbon dioxide emissions, of which nearly three-quarters come from road transport (International Energy Agency, 2009). Extrapolating from recent rates of increase in travel demand, and recent rates of increase in vehicle efficiency, global road transport emissions may approximately treble by 2050 (International Energy Agency, 2009; King, 2007; Sperling & Gordon, 2009).

The situation appears even starker when emissions are considered on a cumulative basis. Global temperature rise due to greenhouse gas emissions over the long term will be proportional to the total amount of CO₂ emitted (Allen et al., 2009; England, Sen Gupta, & Pitman, 2009; Meinshausen et al., 2009; Matthews & Caldeira, 2008; Matthews et al., 2009; Solomon, Plattner, Knutti & Friedlingstein, 2009; Zickfeld, Eby, Matthews, & Weaver, 2009). It is the *area under the curve* of annual emissions that will determine the global temperature rise. Any given probability of exceeding a targeted maximum temperature rise implies a maximum limit on the cumulative total of CO₂ that can be emitted: a total *CO₂ emissions budget* (Hare, 1997). Such total budgets must be divided between global regions or nations, and between sectors of human activity. Table 1-1 summarises a range of estimates of the cumulative CO₂ totals that can be emitted by the light and heavy duty road transport sectors from 2000-2050, globally and in three key regions (Skippon, Veeraraghavan, Ma, Gadd, & Tait, 2012). Modelling of the abatement potential of various options for light and heavy duty road transport in Europe and the USA shows that a wide

range of technological and behavioural measures will be needed if cumulative CO₂ emissions are to be kept within these budgets (Skippon et al., 2012).

Region	Well-to-Wheels budget for 2000-2050, GtCO ₂		
	Total	Light duty	Heavy duty
World	198 - 250	130.9 – 164.8	67.5 – 85.2
US	19 - 45	15.0 – 35.4	4.1 – 9.7
Europe	18 - 25	12.1 – 16.8	5.9 - 8.3
China	10 - 75	10.8 – 21.9	26.5 – 53.5

Table 1-1. Regional light and heavy duty CO₂ emission budgets (maximum total cumulative CO₂ emissions to achieve 50% chance of limiting global temperature rise to 2°C) (from Skippon et al., 2012)

Low-carbon vehicle technologies

One of the ways the automotive and fuels industries are responding to this challenge is by developing a range of low-carbon vehicle and fuel technologies, including vehicles powered by hydrogen (Ehsani, Gao, & Emadi, 2009; Koca, 2010; Rifkin, 2002), electricity stored in batteries (Ehsani et al., 2009; Sperling, Delucchi, Davis, & Burke, 1994), gaseous fuels such as liquefied natural gas and compressed natural gas (Bechtold, 1997), methanol (Olah, Goeppert, & Prakash, 2006), and biofuels (Organization for Economic Co-operation and Development, 2004; Reijnders & Huijbregts, 2009; Worldwatch Institute, 2007). Thus in the coming decades consumers will encounter a range of new vehicles and fuels.

The success of these new technologies in reducing road transport carbon dioxide emissions will depend critically on their uptake by consumers. If new low-carbon vehicle/fuel combinations meet or exceed consumers’ needs, uptake is likely to be high, impacting favourably on carbon dioxide emissions. However if they fail to meet consumers’ needs, uptake may be low, having little impact on carbon dioxide emissions. The question of how consumers will respond to the various attributes

and characteristics of these new low-carbon vehicle/fuel combinations is therefore of some importance.

Electric vehicles

At present the leading contender for radical change in vehicle technology appears to be the plug-in electric vehicle (EV) (King, 2007). EVs represent a spectrum of emerging vehicle technologies powered by electricity drawn from the electrical grid. There are three broad categories. The first category is Battery Electric Vehicles (BEVs), which are powered solely by electricity; the battery must have sufficient charge for the vehicle to operate, because BEVs have no internal combustion engine (ICE), and therefore they require regular recharging. Present (2014) BEVs have ranges (the distance that can be travelled before an initially fully charged battery is depleted) of around 150km in urban driving, but only around half that in high-speed cruising. In contrast, the second category, Plug-in Hybrid Electric Vehicles (PHEVs) have both electric and ICE power-trains that operate in parallel, both providing power to the road wheels. These can cover an initial distance, say 15-50 km (in urban driving), under electric power only, and then switch to hybrid operation. In hybrid mode they maintain a small reserve of charge in the battery so that the electric motor can power the vehicle for short distances at low speeds, and supplement the ICE during acceleration transients or other high-load situations such as hill climbs. At higher cruising speeds, the ICE alone powers the vehicle (and may also operate a generator to recharge the battery). PHEVs differ from their cousins, Hybrid Electric Vehicles (HEVs) such as the gasoline-fuelled conventional Toyota Prius or the diesel-fuelled Peugeot 3008 Hybrid4, in that HEVs have smaller batteries that cannot be charged directly from the mains electricity supply - the only external source of energy is liquid fuel: the relatively small battery is charged by the ICE, for instance via an alternator (for this reason, I do not include HEVs as EVs in this thesis: I assume that HEVs tend to be experienced and construed by their users as more-efficient conventional cars, rather than as a new and qualitatively different category of vehicle). The third category is Extended-Range Electric Vehicles (E-REVs). These also combine electric and ICE powertrains in the same vehicle, but they are configured in series rather than parallel, so that only the electric motor directly powers the road wheels. An E-REV runs under electric power from its battery until the battery is depleted; at that stage, the ICE

starts up, and provides power for the electric motor via a generator. Typically, the battery is not recharged via the generator – it remains depleted until it is recharged from an external electricity source, except for a small buffer capacity that enables the battery to supply instantaneous power demand more quickly than the ICE. Present E-REVs have electric ranges up to around 60km in urban driving. All three types of EV, along with HEVs, make use of regenerative braking, in which energy that would normally be lost through braking is recovered and used to partially recharge the battery. This increases their overall efficiency in urban driving, although less so during cruising (where braking events are less frequent). All three technologies are currently on the market: for example the Nissan Leaf and Renault Fluence BEVs; the plug-in Toyota Prius PHEV; and the Chevrolet Volt (USA) / Vauxhall/Opel Ampera (Europe) E-REV. To date they have been substantially more expensive than ICE cars and have sold in limited quantities (several thousands in the USA, Europe and Japan).

At present, mainstream consumers (as opposed to those especially favourably disposed towards early adoption of EVs) have tended to see the short range of BEVs on a single battery charge, and the extended down-time while recharging, as significant barriers to uptake (Skippon & Garwood, 2011; Graham-Rowe, Gardner, Abraham, Skippon, Dittmar, Hutchins, et al., 2012). PHEVs and E-REVs, which do not have these disadvantages, seem much more likely to appeal to consumer drivers (Energy Technologies Institute, 2013). However, the need for two powertrains in the same vehicle will mean that they continue to carry a cost premium over conventional ICE vehicles. To displace a significant fraction of ICE vehicles from the global vehicle parc, they will need to offer consumer drivers advantages over conventional vehicles that offset this cost disadvantage.

The role of performance in electric vehicle uptake

For some drivers, performance is a key attribute of cars. There is a genre of car magazines emphasising performance: in the UK, *Octane*, *Evo*, *Top Gear* and *Autocar* regularly feature performance-oriented articles. There is a similar genre of books emphasizing performance: *Sports Cars*, *High-Performance Machines* (Cheetham, 2003); *Ultimate Performance Cars* (Cheetham, 2005); *BMW, Precision and Performance* (Cockerham, 1997); *Beasts from the East: Japan's*

ultimate performance cars (Guinness, 2005); *Muscle, America's Legendary Performance Cars* (Leffingwell, Holmstrom, Newhardt, 2008); *A-Z Japanese Performance Cars* (Rees, 2005). The language used in some of these publications suggests, on the one hand, an affective value to performance: "No other automotive experience matches the magic of executing a perfect second-third speed shift in a fast muscle car...It's exciting, thrilling and intense..." (Leffingwell et al., 2008, p10); and on the other hand, a symbolic value: "Having a 'Beemer'¹ meant that you had arrived, and had an appreciation for the performance and engineering elegance found in these cars" (Cockerham, 1997, p11).

This emphasis on performance is not restricted to a small segment of highly car-oriented drivers, but is also a factor in mainstream car choice. To illustrate this, consider the product reviews offered by the Parker's Guide website in the UK (Parker's Guide, 2010), a popular buyers' guide for used, rather than new cars. These reviews described cars under five headings, "Driving and Performance", "Comfort", "Safety and Reliability", "Buying & Selling", and "Costs", with "Driving and Performance" notably heading the list.

This perspective suggests that meeting consumers' needs, wishes and requirements for vehicle performance better than a conventional ICE vehicle might be an important factor in the success of EVs, helping to offset the disadvantage of higher cost. Responses by mainstream consumer drivers to the performance of recent BEVs and PHEVs have been mixed (Skippon & Garwood, 2011; Graham-Rowe et al., 2012) but, as we shall see in Chapter Eleven, the present generation of vehicles is perceived as offering clear performance benefits compared with equivalent ICE vehicles.

¹ "Beemer" is a colloquial reference to a car carrying the BMW brand.

Research questions

My thesis will therefore explore how consumers experience vehicle performance. I shall consider three research questions:

1. What does vehicle performance mean to consumer drivers, and what aspects of it matter most to them?
2. What influences consumer drivers' perceptions of those aspects of performance, in normal driving? What differences in those aspects can consumer drivers perceive?
3. How do consumer drivers value those aspects of performance?

My overall aim is to provide a comprehensive picture of vehicle performance as understood and experienced by consumer drivers, to inform the future design of EVs.

Thesis structure

The first of the research questions is addressed in Chapters Two and Three. I shall begin by reviewing the literature relevant to the question of what performance means to consumer drivers, and then use qualitative methods to develop a model of how consumer drivers construe vehicle performance. The second question is addressed in Chapters Four to Seven. In Chapter Four, I shall develop a theory for the perception of available vehicle performance. Since perception of available vehicle performance depends on the opportunities to experience that performance afforded by driving behaviours, I shall also introduce a new theory of driver behaviour, based on the simultaneous pursuit of multiple goals. In Chapters Five and Six I shall test these theories, and use driving simulation and test track experiments to measure how far consumer drivers can directly perceive differences in acceleration, an aspect of performance that is central in the model developed in Chapter Three. Chapter Seven will use driving simulation to investigate implicit perception of smaller differences in acceleration. Chapters Eight, Nine and Ten address the third question, extending the traditional discussion of value by exploring the *symbolic* value of aspects of vehicle performance - what having a car with a particular level of performance says about the person who owns or drives it. These chapters introduce two novel methods for characterising the

symbolic meaning of consumer products, their attributes and the ways they are used. The three lines of inquiry will be brought together in Chapter Eleven, which describes a randomized controlled trial in which mass-market consumer drivers' responses to modern BEVs and equivalent ICE cars are compared, including their ratings of performance and the symbolic meanings they attribute to each type. Chapter Twelve will conclude the thesis by summarising the main findings in relation to the three research questions.

Investigation of each of the three research questions required different theoretical and empirical approaches, and access to several research literatures that overlap rather little. Accordingly I have not followed the traditional thesis structure, starting with literature review and theory chapters and then following those with empirical chapters; rather, I have introduced the appropriate literature and theory prior to the empirical research to which it relates.

Chapter Two. What does vehicle performance mean to consumer drivers? A review of the literature

I first consider the question, what does “performance” mean to consumer drivers? To begin, I briefly review how the automotive and fuels industries have approached this issue, and what evidence the academic literature provides.

In the main, the industries have made their own assumptions about how drivers construe performance, rather than eliciting consumers’ own constructs; and while there are some commonalities, there is surprisingly little consensus about what exactly contributes to drivers’ subjective perceptions.

My focus is on aspects of performance that can be affected by the vehicle’s powertrain and/or fuel. Thus, although they may also be important to consumers, I shall not consider aspects of performance that depend on steering, suspension or braking systems, such as cornering, ride comfort or brake efficiency. Powertrain-related performance refers to how the vehicle’s longitudinal motion, speed, acceleration, etc., respond to the driver’s control actions using the accelerator pedal and gears. From consumers’ perspectives, there may be some interaction between powertrain performance and braking system performance, in the sense that “engine braking” is sometimes used by drivers to slow an ICE vehicle, and regenerative braking is a feature of EVs. Likewise, consumers may be aware that power from the engine is used in many vehicles to support steering systems. I shall consider such linkages only to the extent that they are made by consumers themselves.

In the automotive industry it is common to define powertrain performance in terms of objective engineering variables that can be measured directly. Wei, Pisu, Rizzoni, and Yurkovich, (2003) and Wei and Rizzoni (2004) identified the following set of variables as suitable for the objective characterization of performance:

- Acceleration (0-60mph; 30-50mph; 50-70mph)
- Top speed
- Gradeability Limit (the maximum gradient at which vehicle can just move forward)
- Gradeability at fixed speed (the maximum gradient at which that speed can be maintained)
- Towing capability (how much mass a vehicle can tow under specified conditions)

This approach has the benefits of ease of measurement, and ability to represent performance using these variables in vehicle simulation models, but it does not follow that consumer drivers would construe vehicle performance in this way. For example, it seems unlikely that many consumers engage, during their normal driving, in finding the maximum gradients at which their vehicles will just move forward.

The automotive industry has also attempted to compare objective engineering measures with drivers' subjective evaluations of aspects of vehicle performance, with a view to being then able to use the former as design tools that can predict consumer response to vehicle performance. For example, Passmore, Patel, and Lorentzen (2001) reported an experimental study in which subjective ratings of performance were compared as engine performance variables were varied. Their subjective response variables were: overall performance, responsiveness to accelerator depression, "smooth acceleration", "quick off the mark", "good acceleration through the gears", and "ease of control of available power". The authors argued (p.510) that "response variables that can be interpreted by the subjects in a relatively loose fashion are generally considered to be the most reliable" but otherwise did not discuss how they chose this set. Performance was rated by expert drivers, using these variables, at several levels of the engine parameters *wide-open-throttle acceleration*², *throttle progression*³, and *part-throttle rate of change of acceleration with engine*

² Acceleration with the throttle fully open, typically corresponding to the control condition of having the accelerator pedal fully depressed.

³ Throttle progression refers to the rate of change of engine torque with accelerator pedal depression.

speed. Subjective ratings were found to cluster into two groups: ratings of smooth acceleration and “ease of control of available power” in one group, ratings of the remaining variables in the other.

This kind of approach is one step closer to an understanding of consumers’ perspectives on performance. It enables automotive engineers to relate objective measures of performance to drivers’ subjective ratings of performance. However the rating variables and scales are supplied by the researchers, not elicited from consumer drivers, so they may not offer a direct window onto how consumer drivers themselves construe performance.

It might be expected that automotive manufacturers, and fuel suppliers, will have conducted extensive market research on consumer drivers’ own performance constructs. However their market research tends not be published, as it is seen as commercially sensitive. In addition, the objectives of commercial market research tend towards capturing actionable “insight” as rapidly as possible; so the research is not necessarily carried out with the same rigour as academic research. This is particularly the case with qualitative research, where the academic processes of transcription and detailed analysis tend to be too slow for commercial purposes, so reports of in-depth interviews and focus groups are often based on researchers’ subjective impressions and written notes made during sessions (Puchta & Potter, 2004; Gordon & Langmaid, 1988; Keegan, 2006). I have reviewed the confidential commercial market research carried out by Shell in support of its premium fuel brands, Shell V-Power and Shell V-Power Diesel. Whilst this body of research is appropriate in relation to its commercial goals, it has tended to *assume* how performance is construed by consumers, rather than eliciting performance constructs from consumers themselves. My informal discussions with staff in automotive manufacturing companies, automotive consultancies and other fuel suppliers have suggested a similar picture. Thus even if the commercial market research on vehicle performance were publicly available, which it is not, it would be unlikely to contribute towards the specific needs of this research.

There is, however, a small body of academic research on the reasons consumer drivers offer for their car use (a literature that, in the main, is aimed at helping to find ways to reduce car use). It seems reasonable to suppose that, if vehicle performance matters to consumer drivers, how they construe performance might figure in their accounts of why they use cars. Mann and Abraham

(2006) explored the role of affect (emotion) in peoples' transport mode choices, while Gardner and Abraham (2007) looked at peoples' reasons for car use. Both of these were UK-based studies. They found that affective and symbolic factors, such as independence and personal freedom, personal control, personal space, and enjoyment, were very important. For some drivers, the experience of driving *per se* was pleasurable. Hiscock, Macintyre, Kearns, and Ellaway (2002) found that Scottish drivers' attachments to cars were related to perceived psycho-social benefits: the protection cars offer from undesirable people and events; the autonomy offered by the convenience, reliability, and access to more destinations of car travel; and the prestige and other socially desirable personal attributes conveyed by car use. In a later study Ellaway, Macintyre, Hiscock, and Kearns (2003) found that being a car driver conferred more of these benefits than being a passenger; and also that, for men only, driving conferred an additional psycho-social benefit of higher self-esteem. Redshaw (2008) interviewed young drivers in Australia in a study of "car cultures". She found that young drivers associated car use with certain sets of cultural meanings: their car use, and their choices of car, signified aspects of identity, particularly masculinity and sexual maturity. Not all cars offer the same set of psycho-social benefits. Heffner, Kurani, and Turrentine (2007) explored symbolism in peoples' choices to buy Toyota Prius hybrids in California. They found that people bought and used the Prius hybrid specifically because doing so put them in a positive light as intelligent, moral people who care about others.

The emphasis in these studies has thus been on wider factors that contribute to the value of car use. Although enjoyment of driving was a motivating factor in several of these studies, they did not explore in detail how enjoyment might be linked to specific aspects of vehicle performance; so they do not illuminate my question of how drivers construe performance.

One remaining approach to understanding how drivers construe performance is to consider the literature on "driveability". While performance can be seen as the way a vehicle responds to control actions by the driver, driveability reflects the ability of a vehicle to operate satisfactorily, without demerits that are noticed by the driver, in response to the driver's control actions, over a range of climatic conditions and driving situations. It is, in a sense, the resilience of a vehicle to loss of performance. Given the phenomenon of loss aversion, in which people attach more subjective

value to losses than to gains (Kahneman & Tversky, 1979), it might be expected that consumers would place more emphasis on performance demerits than on performance improvements. Understanding how consumers construe driveability, then, might be an indirect route to understanding how consumers construe performance.

Whereas performance has tended to be viewed in the automotive industry as a set of objective properties of the vehicle, driveability is typically defined in terms of the subjective experience of drivers. A vehicle has poor driveability if drivers notice a significant number of demerits, such as misfiring or hesitation when they depress the accelerator pedal; and it has good driveability if drivers notice no demerits. Given this subjectivity, there are individual differences in drivers' sensitivity to driveability; so generally it is evaluated by expert assessors. It is usually assumed in the literature that consumer drivers, while not as discriminating or consistent in their evaluations as expert assessors, will have the same priorities in terms of performance demerits. I make the further assumption that models of driveability will therefore capture aspects of performance that are thought to relate to consumer drivers' perceptions. Table 2-1 lists various attributes of driveability that have been included in recent papers. The most comprehensive, multi-parameter model is the AVL-Drive model, with over 270 individual parameters measured over a range of vehicle operating modes (List & Schoegg, 1998; Schoegg, Ramschak, & Bogner, 2001). The authors claim to have detailed correlation data linking each parameter to subjective evaluations of driveability by consumer drivers, though the details are not reported. However my experience in qualitative market research interviews suggests that consumer drivers' own conceptualizations of performance do not have this degree of fine structure.

Variables connected with lack of smoothness (stumble, shuffle, jerk, roughness, etc.); responsiveness (hesitation, tip-in response, sluggishness); acceleration, noise, and starting behaviour occur often in Table 2-1. These appear to be the main component attributes of driveability, so, if my assumption is correct, the automotive industry sees these as the aspects of performance that matter most to consumers. However, a striking feature of Table 2-1 is the wide range of specific parameters in different models. Given that all are supposed to represent something that is perceived by consumer drivers, it is surprising how little consensus there is in the literature

about what exactly it is that contributes to drivers' subjective perceptions of driveability. Further, even when consumers' subjective assessments have been considered, the driveability parameters have invariably been defined by the researchers. There appears to be little in the driveability literature to reflect consumers' own construal of what constitutes driveability.

In summary, there are various conceptualizations of vehicle performance and/or driveability in the automotive and fuels industries, and acceleration, responsiveness, noise and smoothness tend to be seen as important factors. However, these conceptualizations have almost invariably been constructed by engineers and researchers rather than elicited from consumers. This runs the risk of requiring participants to try to fit their own conceptualizations onto those the researchers supply, however good or bad the fit: "forcing 'subjects' onto a... bed of Procrustes" (Salmon, 2003, p311-318). This is unsatisfactory and could be quite misleading. However there has been very little published research on how consumer drivers themselves represent or construe vehicle performance. One of the goals of my research will be to fill this gap.

Reference	Summary of content	Driveability attributes included
Buczynsky (1993)	Comparison of fuels based on subjective ratings of driver satisfaction. Hesitation was the most commonly reported demerit.	Hard starts; start-up stall; idle stalls; driving stalls; rough idle; hesitation ⁴ ; sluggishness
Chio, Song, Lee, & Cho (2003)	Development of a model for vehicle dynamic response analysis, based on experimental procedures to measure engine torque and investigate shuffle characteristics at tip-in in 2 nd and 3 rd gear.	Shuffle ⁵
Dorey & Holmes (1999)	Development of objective metrics aimed at understanding and characterizing driveability	Start time; start quality; idle stability; idle NVH ⁶ ; idle drive; pull-away; tip-in/back-out ⁷ (city) tip-in/back-out (highway); cruise 2000/3000 rpm; full load performance; acceleration from low to high speeds; pedal response; gearshifts; engine response in neutral
Dorey & Martin (2000)	Development of driveability assessment tools	Engine start; Engine idle response; Tip-in/Back-out response
Jantos, Brol, & Mamala (2007)	Development of a device for determining driveability of vehicles, based on longitudinal acceleration and taking vehicle pitch into account.	Acceleration; vehicle pitch change during acceleration

Table 2-1. Factors included in evaluation/assessment of driveability in recent papers

⁴ Hesitation refers to momentary failure of an engine to respond during accelerator pedal depression.

⁵ Shuffle refers to oscillations in speed after a change in accelerator pedal depression.

⁶ NVH refers to Noise, Vibration & Harshness.

⁷ Tip-in refers to depression of the accelerator pedal. Back-out refers to release of the accelerator pedal.

Reference	Summary of content	Driveability attributes included
Jewitt, Gibbs, & Evans (2005)	Study of the effect of gasoline ethanol content, on cold-start and warm-up driveability of US cars	Hesitation; Stumble ⁸ ; Surge ⁹ ; Backfiring; Stalling
Kiessling (1993)	Demonstration that the inter-rater reliability of subjective assessments of driveability can be improved by adding artificially induced demerits to the round-robin testing	Stumble, hesitation, surge
Kono, Fukumoto, Iizuka, & Takeda (2006)	Effects of Fatty Acid Methyl Ester content of diesel on the cold weather driveability of 2 tonne trucks	Maintenance of fixed speed (50kph) for up to 1 hour
List & Schoeggel (1998)	Development of the AVL-Drive system for assessing driveability, claiming over 100 driveability parameters, grouped into 12 “global vehicle operation modes” but with no specific details	Idle; Engine start; Tip in; Let off; Acceleration; Closed throttle behaviour; Roll on stop; Warm up behaviour; Pedal steering control; Gear change; WOT low end torque; Constant speed part load
McArraragher, Thompson, Bazzani, Aarnink, Kwon, Martinez, Zemroch, et al., (2004)	Effect of gasoline volatility and ethanol content on the driveability of modern (2004) European vehicles	Stalling when starting; Stalling when idling; Stalling under load; Stalling when decelerating; Fail; Roughness; Hesitation; Stumble; Surge; Backfire; Odour
Mo, Beaumont, & Powell (1996)	Development of active driveability control algorithm to reduce shuffle	Shuffle

Table 2-1 (cont.). Factors included in evaluation/assessment of driveability in recent papers

⁸ Stumble refers to failure of the engine to respond smoothly to changes in accelerator pedal depression, typically more severe than hesitation.

⁹ Surge refers to unpredictable variations in engine speed at constant accelerator pedal depression.

Reference	Summary of content	Driveability attributes included
Schoegg et al. (2001)	Development of an on-board system to optimize the calibration of a vehicle by using AVL-Drive assessment during specific test drive manoeuvres carried out by individual drivers.	Rating based on: Idle; Engine start; Cruising; Normal drive; Acceleration; Tip in; Tip out; Motoring; Gear Shift; Drive away/stop; Idle response; Shut off; Vibration; Noise; Warm up
Wei & Rizzoni (2004)	Summary of objective measures for performance and driveability	Interior noise level; Vibration acceleration RMS value; Vibration dose value; Maximum transient vibration value; Tip-in/tip-out response; Acceleration-deceleration jerk
Wicke, Brace, & Vaughan (2000)	Subjective-objective ratings of performance of vehicles equipped with continuously variable transmission (CVT)	Launch Feel; Overall Performance Feel. Derived from 14 questionnaire items that were not reported

Table 2-1 (cont.). Factors included in evaluation/assessment of driveability in recent papers

Chapter Three. How consumer drivers construe vehicle performance

In this chapter I use the findings of a qualitative study with UK drivers to build a model of how consumer drivers construe vehicle performance.

Methodology

An adapted repertory grid methodology (Fransella, Bell, & Bannister, 2004; Jankowicz, 2004) was used for the study. This approach was chosen: (1) to elicit drivers' own concepts of vehicle performance, rather than imposing researchers' constructs and implicit models; (2) to identify ways of construing vehicle performance that consumer drivers have *in common*; and (3) to identify the *relationships* between aspects of drivers' concepts of vehicle performance. Quantitative methods such as questionnaires are unsuitable when considered against these criteria. Various qualitative methods could in principle meet requirement (1). For instance, Interpretive Phenomenological Analysis (Langdrige, 2007; Smith, Flowers, & Larkin, 2009), which focuses on the lived experience, might be used for exploring what it feels like to experience vehicle performance, but it cannot identify the extent to which themes elicited are held in common, nor establish the relationships between them. Grounded theory methods (Glaser & Strauss, 1967; Strauss & Corbin, 1998) provide structured analyses that can identify hierarchical relationships between themes. However a pilot study using this approach did not elicit a particularly rich set of themes, and the interpretation of their relationships remained subjective.

The repertory grid method, which elicits the specific constructs used by an individual in construing and making sense of a topic, meets all three requirements. Although rarely used in transport research to date, it has been used in education (Walker & Winter, 2007); business psychology (Stewart & Stewart, 1981); marketing research (Heine, 2009; Marsden & Littler, 2000; Rogers & Ryals, 2007), information systems research (Tan, Tung, & Xu, 2007), and in ergonomics to study how people interact with product features (Baber, 2004; Stanton & Young, 1999). The method is based on Kelly's (1955) personal construct theory, which assumes that people construe aspects of

the world in terms of contrasts, such as: *Pleasant vs. Rude*; *A good teacher vs. An ineffective teacher*; *Ensures I've understood her point vs. Doesn't check if she's made sense*; ... (Jankowitz, 2004). Both the left and right poles of these personal constructs are needed in order to understand their meanings: the opposing poles are not necessarily simply negations of each other. "Pleasant", for example, could be contrasted with a range of potential opposites: for example nasty, grumpy, withdrawn, etc.

Although there have been challenges concerning whether mental constructs are genuinely bipolar (Frost, 1982; Goodrich, 1999), there is evidence supporting bipolar structure (Millis & Neimeyer, 1990; Reimann, 1990; Sewell, 2003; Walker, 2003; Walker, Ramsey, & Bell, 1988). It is not necessary to take a position in this debate to be able to use repertory grids as an elicitation technique.

Basic repertory Grid method

In the basic repertory grid method, constructs are elicited by presenting the participant with examples, referred to as "elements", representing the topic of interest, and asking the participant to identify ways in which the examples are similar, and ways in which they differ. This establishes one pole of a construct. The researcher then asks "and what is the opposite of that?" to establish the opposing pole of the construct. Constructs are assumed to have a "range of convenience" (Kelly, 1955), a range of applicability or relevance. Some have very wide applicability (e.g. "good" vs. "bad") while others have a much narrower relevance (e.g. "can carry all of our holiday luggage" vs. "can't fit a weekly supermarket shop in the boot"). Difference in range of convenience is one way in which constructs form a hierarchy, in which some constructs are super-ordinate (more global or general in application) and some are subordinate (more localised or specific in application). Super-ordinate and subordinate relationships between constructs are elicited by the researcher using laddering (successively seeking ever-more specific ways of expressing constructs) and pyramiding (examining and expanding on each pole of an elicited construct separately) (Fransella et al., 2004; Jankowicz, 2004). Table 3-1 shows how constructs are recorded in a repertory grid. The columns represent the elements, in this case a range of different vehicles. The rows represent the constructs elicited from the participant, with opposing poles on either side of the central table.

	Sports car	Small hatchback	Family hatchback (petrol)	Family hatchback (diesel)	Executive saloon	People carrier	Sports Utility vehicle	Transit Van	
Confidence that the car has power available when I want to overtake	5	2	3	3	4	2	1	1	I don't expect to be able to overtake
Consistent and reliable response to the accelerator pedal	5	4	5	5	5	4	3	3	Inconsistent and unpredictable response to the accelerator pedal
Catch up to car in front quickly as you accelerate to overtake, so you can go ahead and overtake	5	2	3	3	4	2	1	1	Slow to catch up to car in front as you accelerate to overtake, so you may have to abort
Feels safe when committed to overtaking: sense of short time to return to safety	5	2	3	3	4	2	1	1	Feels risky when committed to overtaking: sense of long time before return to safety
Feel confident to overtake often	5	2	3	3	4	2	2	1	Feel reluctant to overtake
Engine sounds quiet during acceleration	2	2	3	3	4	3	3	3	Engine sounds loud during acceleration
Responds immediately when you put your foot down	5	2	2	3	4	3	2	1	Nothing happens at first when you put your foot down
Refined smooth feel	4	2	4	3	5	4	2	2	Uncomfortable jerky feel
Pleasant low pitched rumble	5	2	3	2	5	3	1	1	Unpleasant high pitched asthmatic whine

Table 3-1. Example of a Repertory Grid

The method can also explore how participants *use* constructs in their thinking about the topic, by asking them to give a rating for each element on each construct using a numerical scale (with the opposing poles representing the ends of the scale). For example, in Table 3-1 vehicles are rated on

the construct “refined smooth feel” vs. “uncomfortable jerky feel” on a five-point scale, with 1 indicating “uncomfortable jerky feel” and 5 indicating “refined smooth feel”. A small hatchback scores 2 on this scale, an executive saloon scores 5. Scores for each element on each construct are recorded on the Grid. The scores are indicative of how the individual uses the construct. Further, if a participant gives the same set of scores for each element on two constructs, then he/she tends to use the two constructs in a closely related way. Analysis of the similarities and differences in score patterns can therefore be used to identify relationships between constructs.

Adapted repertory Grid method

In this study, conventional repertory grid technique was adapted in two ways to address requirement (2), to identify ways of construing vehicle performance that consumer drivers have in common. Firstly, constructs were elicited from triads (groups of three participants) rather than individuals. Triads built their grids of constructs as a collective endeavour, discussing the meaning of each construct between them. This was intended to enable participants to prompt and stimulate each other’s construals, and to negotiate construct definitions that reflected commonalities in their construing of vehicle performance.

Secondly, thematic analysis of the ensemble of elicited constructs was used to group them into semantically related themes; and weighting procedures were used to prioritise those themes that recurred most frequently among the triads and were assessed as most important by the participants.

The repertory grid method also met requirement (3), by using cluster analysis to identify groups of constructs that are used in a similar way. The use of cluster analyses was qualitative and thematic rather than quantitative, in keeping with the exploratory nature of the study (and different from the typical use of cluster analysis in transportation research, to identify segments of participants who exhibit similar patterns of responses to questionnaires). The approach was to conduct cluster analyses of each grid, and then compare graphical outputs (dendograms) subjectively for commonalities of structure.

Differences among drivers

Study 1¹⁰ was conducted with UK drivers. In many markets, e.g. in Europe, passenger cars and vans are available with either spark-ignition engines (fuelled with gasoline) or compression-ignition engines (fuelled with diesel). These tend to have different performance characteristics, so it was plausible, a priori, that drivers of each type might construe performance differently. To explore this, drivers of both types were included, and their construals analysed separately. There is also some evidence that cars and driving have different meanings for men and women (e.g. Redshaw, 2008), so it was also plausible that they might construe the performance of vehicles differently. To explore this, participants of both genders were included, and their construals also analysed separately.

A pilot study had suggested that performance-oriented drivers tended to be better able to articulate what performance meant to them, with a richer language of terms, than less performance-oriented drivers. Accordingly this study focussed on the way drivers who self-reported that vehicle performance was important to them construed performance.

Method

Participants

The 48 UK participants, aged from 30 to 55, each rated vehicle performance as “important” or “very important” to them in a screener question at recruitment. Half used gasoline-fuelled cars and half used diesel-fuelled cars, ranging from small hatchbacks, through family cars to high performance cars. Half of the users of each vehicle type were male, half female. Each triad consisted of drivers of the same gender, using the same vehicle type (four triads for each

¹⁰ Studies and Experiments are numbered in sequence throughout the thesis. I shall refer to controlled experiments in the laboratory, in a driving simulator, or on a test track as “Experiment X”, etc. and alternative designs as “Study Y”, etc.

gender/fuel combination). Participants were randomly allocated to one of the four triads appropriate for their gender and vehicle type.

Repertory grid elements

The set of elements used in the grids comprised eight different classes of vehicles, which were intended to be familiar to a majority of UK drivers, and to be understood to differ in terms of performance. They were: Sports car; Small hatchback; Family hatchback (petrol); Family hatchback (diesel); Executive saloon; 4x4 (Sports Utility Vehicle); People Carrier (Multi-Purpose Vehicle, MPV); and Transit Van (representing the category of panel van, of which the Ford Transit is a familiar example in the UK).

Procedure

Each triad session lasted approximately 2 hours 30 minutes. After a brief introduction, sessions comprised two parts of equal duration: an initial discussion of vehicle performance, using various stimulus materials; followed by a repertory grid exercise. Sessions were recorded on video and audio.

Initial discussion

The initial discussion was intended to maximise the mental activation of participants' constructs about the topic of vehicle performance so they would be readily accessible to recall in the repertory grid session. Participants were led through a discussion about vehicle performance, types of vehicles, driving situations, etc., using stimulus materials that included verbatim quotes from other drivers, and video clips of driving situations, drawn from audio-visual recordings of accompanied drives in earlier research by the author.

Repertory grid elicitation

Participants were introduced to the repertory grids procedure and each given a grid form to complete. Groups of three prompt cards, each showing the name of one of the vehicle classes, were shown to the participants, who were asked to identify a way in which two were similar, and

different from the third, in terms of their performance. The triad then discussed and negotiated ways in which the performance of the vehicle classes was similar / different. Whenever the first pole of a construct was identified by the triad, the researcher prompted “what is the opposite of that?” to elicit the opposing pole. Where genuine differences in construal occurred between triad members, they recorded separate constructs. Prompts (“any other ways in which the performance of two of these is different from the third?”) and laddering and pyramiding questions were used to explore the level of detail of participants’ constructs. When no more constructs were forthcoming from the initial three elements, participants were shown a further set of three, and the process was repeated.

Analysis

Thematic analysis of constructs

Thematic analysis was conducted separately for the users of gasoline-fuelled and diesel-fuelled cars.

Many constructs were elicited from the eight triads in each arm of the study. The full set of constructs elicited from the 8 triads in each analysis was grouped into a smaller set of themes, which were internally homogeneous (all constructs allocated to a particular theme are closer in meaning to each other than they are to any constructs allocated to different themes) and externally heterogeneous (all constructs allocated to different themes are more different in meaning than any of the constructs within a particular theme). Themes identified through this process represented bipolar constructs that drivers use in understanding and mentally representing vehicle performance, at a level of generalisation where they could be thought of as held in common by many drivers.

The analysis was approached inductively (Braun & Clarke, 2006), i.e. the structure of themes was allowed to emerge from the data itself. It was conducted at a semantic level (Braun & Clarke, 2006), from the explicit meanings contained in the data, without attempting to draw inferences about underlying meanings, and from an essentialist/realist epistemological stance - assuming that the language used by participants reflected their experience and personal constructions in a straightforward way.

To ensure reliability of categorisation, the procedure was carried out independently by two researchers. Their provisional categorisation schemes were compared and negotiated until a common scheme was arrived at. The main issue for negotiation was the saliency of similarities and differences between constructs with respect to the research topic. Where ambiguity was found between the elicited and opposite poles of a construct, priority was given to the elicited pole to categorise that construct. Other thematic ambiguities were resolved by giving priority in interpretation to nouns, noun phrases and verbs over adjectives or adverbs. For instance, a construct containing the noun phrase “responsive acceleration” might arguably relate to either a “responsiveness” theme or an “acceleration” theme: following the prioritisation scheme, it would be interpreted as primarily concerning “acceleration”, with the adjective “responsive” as a secondary qualifier.

Each analyst then independently re-allocated constructs to the common set of themes. The final allocations were compared using Cohen’s Kappa test for agreement, achieving values of 0.93 for the gasoline vehicle user analysis and 0.89 for the diesel vehicle user analysis.

Analysis of relevance of themes

To distinguish the themes that were most important to participants, and those that were common to a majority of participants, themes were given two forms of weighting. The first was *Importance weight*: the reciprocal of the mean ranking that the constructs allocated to that theme were given by participants. A high score on this measure indicated a theme that was, on average, ranked as “important to me” by participants. The second was *Frequency weight*: a score from 1 to 8 based on the number of triads in which one or more constructs allocated to that theme were elicited. A high score on this measure indicated a theme that was referred to by a majority of the triads. These two weighting measures were combined into a single *Relevance Index (RI)* using the formula:

$$\text{Relevance Index} = 10 \times \text{Frequency weight} \times \text{Importance weight} \quad \dots(3.1)$$

Since RI was used only as a guide to the overall relevance of the theme in participants’ construals of performance, values were rounded to the nearest integer to avoid giving a spurious impression of precision, and the factor 10 was included simply to scale the RI scores for ease of use.

Cluster analyses

Cluster analyses were carried out on each of the 48 individual grids using the analysis package RepGrid IV. Similarity between constructs was measured using the Minkowski *City Block* distance metric (Shaw, 1980, p.159). Alternative Minkowski metrics (Everitt, 1974) were not found to offer better discrimination than the City Block metric. The result was a hierarchy for each grid, in which closely related constructs were clustered together first, and the least closely related constructs were clustered last. The hierarchies were represented graphically in the form of dendograms, which were compared subjectively to identify commonalities of cluster structures. This process was carried out separately for the gasoline and diesel vehicle user groups, and for the males and females within each vehicle user group.

Results

Thematic analyses

Gasoline vehicle users

Table 3-2 shows the themes elicited from the gasoline vehicle users, examples of the constructs assigned to each theme, and their frequency weights, importance weights and Relevance Indices. The bipolar form of each theme is shown in the table; but for brevity each theme will henceforth be labelled by its elicited pole only. The themes are listed in order of Relevance Index. The top five themes elicited from gasoline vehicle users (in terms of Relevance Index) were: *Confidence in ability to overtake*; *Acceleration when pulling away*; *Mid-range acceleration*; *Smoothness when cruising*; and *Power*.

Figure 3-1 shows these themes organised in terms of importance and frequency weight. The top right box in the chart represents those themes that had both high importance and high frequency weight.

Theme	Construct: elicited pole	Construct: opposite pole	Frequency weight	Importance weight	Relevance Index
<i>Confidence in ability to overtake vs. hesitant about being able to overtake)</i>	Confident you can overtake when you need to	Hesitant when going to overtake	7	0.20	14
	Being able to overtake very quickly on a country road	Knowing you have to hold back from overtaking			
<i>Acceleration when pulling away vs. sluggish when pulling away</i>	Good “off the line” car 0-60 mph	Bad “off the line”	6	0.24	14
	Quick take off from the lights	Unable to take off fast enough			
<i>Mid-range acceleration when overtaking vs. slow to accelerate when overtaking</i>	Powerful acceleration 30-50mph	Power struggles at 30-50mph	4	0.28	11
	Fast to accelerate when overtaking	Slow acceleration, can’t overtake			
<i>Smoothness when cruising vs. roughness when cruising</i>	Smoothest ride on a long journey	Least smooth ride on a long journey	7	0.15	11
	Smooth on fast/motorway driving	Rough/jerky on fast/motorway driving			
<i>Power vs. generally underpowered</i>	Knowing the car has extra power when pulling onto a road	Not feeling confident when pulling onto a road	5	0.20	10
	Very powerful	Lack of power			
<i>Good overall acceleration across speed range vs. slow to accelerate</i>	Effortlessly accelerate to 70mph	Struggle to accelerate to 70mph	5	0.19	9
	Accelerates quickly 0-60mph	Slow take-off			
<i>Responsiveness to accelerator (gas) pedal vs. slowness to respond</i>	Being able to respond quickly to things that happen	Being unresponsive and slow to respond	3	0.25	8
	Responsive ability to stop and go	Responsiveness sluggish			

Table 3-2. Vehicle performance themes elicited from gasoline vehicle users

Theme	Construct: elicited pole	Construct: opposite pole	Frequency weight	Importance weight	Relevance Index
<i>Power to maintain speed during hill climbs vs. speed fading on hill climbs</i>	More power and strength to climb hills	Less power and strength to climb hills	4	0.16	7
	Car goes up hill easily with not full foot on pedal	Foot to the floor and still not getting anywhere on the hill			
<i>Confidence in safety vs. feeling of insecurity</i>	Safe secure feeling	Lack of safety	3	0.20	6
	Feel safe driving at speed 50-70mph	Concern for safety driving at speed 50-70mph			
<i>Confidence in ability to accelerate vs. feeling that acceleration is inadequate</i>	Confidence in car's responsiveness in acceleration	Lack of confidence in car's responsiveness in acceleration	2	0.29	6
	Confident the acceleration is there when needed	No acceleration, sluggish			
<i>Low noise when cruising vs. intrusive noise when cruising</i>	Quiet at 50-70mph	Noisy at 50-70mph	4	0.29	5
	Comfortable noise level on motorway	Unpleasant noise level on motorway			
<i>Sporty, "growling" noise vs. high pitched irritating noise</i>	Sporty, deep, good noise when accelerating	Bad, industrial whining noise when accelerating	3	0.13	4
	Exciting revving noise	Nagging noise when driving			
<i>Sense of engagement with car vs. detached feeling</i>	Feeling of oneness with the car	Feeling disconnected from the car	2	0.17	3
	Feeling engaged with the road	Out of control – not connected with road			
<i>"Nippiness" in traffic around town vs. sluggish driving around town</i>	Easy nippiness	Uneasy nippiness	2	0.17	3
	Nippy onto a busy roundabout	Slow onto a busy roundabout			
<i>Smoothness when pulling away vs. jerkiness when pulling away</i>	Smooth acceleration when pulling away	Jerky, noisy, sloopy acceleration when pulling away	2	0.16	3
	Most smooth pick-up in heavy traffic	Least smooth pick-up in heavy traffic			

Table 3-2 (cont.). Vehicle performance themes elicited from gasoline vehicle users

Theme	Construct: elicited pole	Construct: opposite pole	Frequency weight	Importance weight	Relevance Index
<i>Smoothness of gear changes vs. jerkiness when changing gear</i>	Smooth gear change at low revs	Needs foot down and high revs before gear change	2	0.14	3
	Moving through the gears smoothly and quickly	Moves through the gears slowly to avoid jerking			
<i>Speed/responsiveness of gear changes on rural roads vs. gear changes that slow the drive</i>	More responsive gear changing down on country roads	Less responsive gear changing down on country roads	2	0.10	2
	Flexible and quick gear changes on winding roads	Slow and unmanageable gear changes			
<i>Pride in car vs. shame or embarrassment</i>	People see my car and move out of the way (motorway)	Sense of shame or embarrassment about my car	1	0.18	2
<i>Confidence in top speed vs. knowing top speed is limited</i>	Knowing my car is very fast (top speed)	Slow top speed	1	0.15	1
<i>Good engine braking vs. ineffective engine braking</i>	Good engine braking	Poor engine braking	1	0.10	1

Table 3-2 (cont.). Vehicle performance themes elicited from gasoline vehicle users

Note: Importance weight refers to mean rank, so themes with low values were ranked as most important. Abbreviated theme labels are shown in italics in the first column

Theme	Construct: elicited pole	Construct: opposite pole	Frequency weight	Importance weight	Relevance Index
Instant <i>responsiveness</i> to accelerator (gas) pedal vs. sluggish response	Instant acceleration	Sluggish acceleration	6	0.28	17
	Instant response	Poor response			
<i>Smoothness when cruising</i> vs. roughness & vibration when cruising	Smooth ride – lack of vibrations	Bumpy ride – bad vibrations	7	0.18	13
	Smoothness on motorway	Rough on motorway			
<i>Comfort</i> on long journeys vs. makes me uncomfortable	Comfortable ride	Uncomfortable ride	6	0.19	11
	Comfortable after long journey	Uncomfortable after long journey			
High <i>top speed</i> vs. low top speed	High top speed	Low top speed	7	0.16	11
	Speedy	Sluggish			
Good <i>overall acceleration</i> across speed range vs. slow to accelerate across speed range	Good acceleration 0-60	Poor acceleration 0-60	6	0.18	11
	Good acceleration	Chugging along			
Calm, <i>low noise</i> interior vs. unpleasantly loud interior	Quiet interior	Noisy interior	6	0.16	9
	Peaceful & calm	Nasty noise			
<i>Power</i> when laden vs. unable to perform when laden	Good torque/pulling power	Poor torque/pulling power	6	0.16	9
	Performs well when laden	Doesn't perform well when laden			
<i>Confidence in Safety</i> vs. feeling of insecurity	Feels safe on motorway	Doesn't feel safe on motorway	4	0.19	7
	Confidence in it	Feel insecure in it			
<i>Acceleration when pulling away</i> vs. slow to accelerate	Good acceleration 0-30	Poor acceleration 0-30	2	0.30	6
	Good performance in town	Poor performance in town			

Table 3-3. Vehicle performance themes elicited from diesel vehicle users

Theme	Construct: elicited pole	Construct: opposite pole	Frequency weight	Importance weight	Relevance Index
<i>Confidence in ability to accelerate vs. sense of being unable to take opportunities</i>	Feel confident pulling out at junction	Lack of confidence pulling out at junction	1	0.50	5
<i>Smoothness of gear changes vs. jerkiness of gear changes</i>	Smooth gear change	Not smooth gear change	2	0.21	4
	Smooth gear changing	Jerky gear changing			
<i>Good mid-range acceleration when overtaking vs. not enough acceleration to overtake</i>	Good at overtaking	Poor at overtaking	2	0.18	4
	Pick-up 40-70 good	Pick-up 40-70 poor			
<i>Power during hill climbs vs. insufficient power to climb hills</i>	Good power on a long hill	Weak on a long hill	3	0.12	4
	Good power up a steep gradient hill	Loses power up a steep gradient hill			
<i>Sporty noise vs. high pitched noise</i>	Good engine noise	Poor engine noise	3	0.10	3
	Grunt noise	Scream noise			
<i>Confidence in ability to overtake vs. hesitancy about ability to overtake</i>	Confidence in overtaking on A road	Lack of confidence in overtaking on A road	2	0.14	3
	Confidence overtaking on motorway	Lacking confidence overtaking on motorway			
	Confidence overtaking on country lanes	Lacking confidence overtaking on country lanes			
<i>Steady acceleration vs. unsteady acceleration</i>	Steady acceleration	Unsteady acceleration	1	0.27	3
<i>Enjoyment of driving vs. boredom</i>	Feels good to be driving	Doesn't feel good to be driving	2	0.13	3
	Lots of fun	Boring			

Table 3-3 (cont.). Vehicle performance themes elicited from diesel vehicle users

Theme	Construct: elicited pole	Construct: opposite pole	Frequency weight	Importance weight	Relevance Index
Quiet, smooth <i>idle noise</i> vs. noisy idling	Purr sound on tick-over	Noisy tick-over	1	0.14	1
Good <i>versatility</i> of performance in different situations vs. performance inadequate in some situations	Good versatility of performance in all driving	Poor versatility – struggles sometimes	1	0.14	1
High <i>efficiency</i> vs. poor efficiency	High efficiency	Poor efficiency	1	0.13	1
<i>Pride in car</i> vs. embarrassment	Aspirational	Don't want to be seen in it	1	0.13	1
<i>High acceleration from high initial speed/gear</i> vs. slow acceleration	Good acceleration 50-70	Poor acceleration 50-70	1	0.10	1

Table 3-3 (cont.). Vehicle performance themes elicited from diesel vehicle users

Note: Importance weight refers to mean rank, so themes with low values were ranked as most important. Abbreviated theme labels are shown in italics in the first column

Theme	Relevance Index	Comparison between	
		Male triads	Female triads
Confidence in ability to overtake	14	3	4
Acceleration when pulling away	14	4	4
Mid-range acceleration	11	4	2
Smoothness when cruising	11	3	3
Power	10	4	4
Overall acceleration	9	4	3
Responsiveness	8	4	1
Power during hill climbs	7	2	3
Confidence in safety	6	2	4
Confidence in ability to accelerate	6	2	2
Low noise when cruising	5	3	3
Sporty noise	4	3	1
Sense of engagement with car	3	3	0
“Nippiness”	3	1	2
Smoothness when pulling away	3	0	2
Smoothness of gear changes	3	1	1
Speed/responsiveness of gear changes	2	0	3
Pride in car	2	1	0
Confidence in top speed	1	1	0
Good engine braking	1	1	0

Table 3-4. Gasoline vehicle users: Consistency across gender

Comparison scheme: 4 = high frequency, high importance for the relevant gender; 3 = high frequency, lower importance; 2 = lower frequency, high importance; 1 = lower frequency, lower importance; 0 = not elicited at all from that gender

Theme	Relevance Index	Elicited in:	
		Male triads	Female triads
Responsiveness	17	3	3
Smoothness when cruising	13	3	4
Comfort	11	3	3
Top speed	11	3	4
Overall acceleration	11	4	2
Low noise	10	2	4
Power	9	4	2
Confidence in safety	7	2	2
Acceleration when pulling away	6	1	1
Confidence in ability to accelerate	5	1	1
Smoothness of gear changes	4	0	2
Mid-range acceleration	4	1	1
Power during hill climbs	4	1	2
Sporty noise	3	0	1
Confidence in ability to overtake	3	3	0
Steady acceleration	3	0	1
Enjoyment of driving	3	2	0
Idle noise	1	1	0
Versatility	1	1	0
Efficiency	1	1	0
Pride in car	1	0	1
High initial speed/gear acceleration	1	1	0

Table 3-5. Diesel vehicle users: Consistency across gender

Comparison scheme as Table 3-4

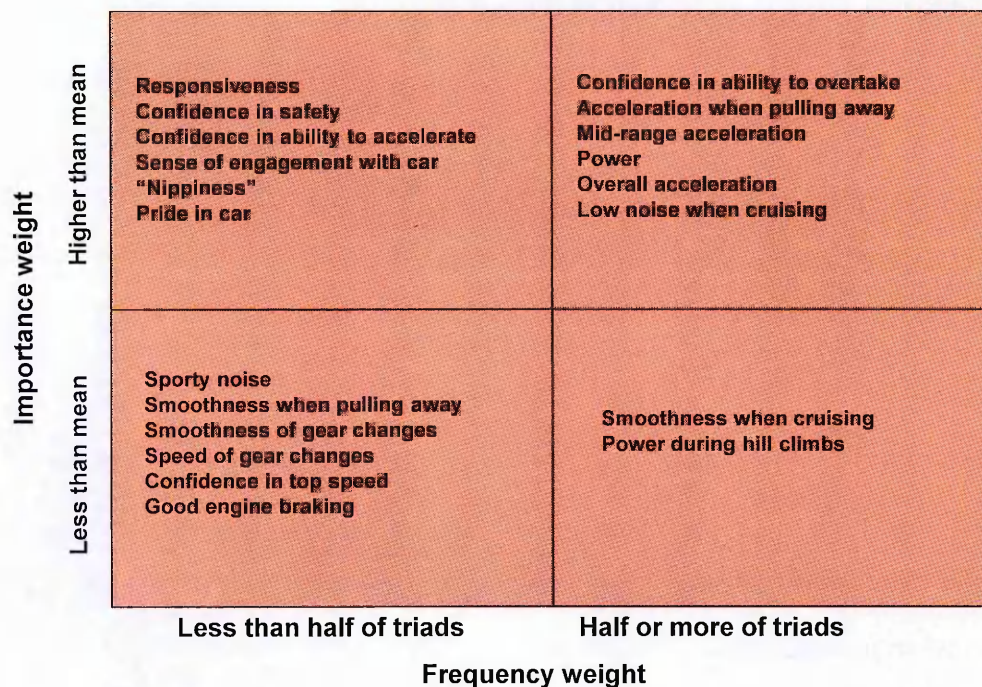


Figure 3-1. Gasoline users' construal of performance: Summary of themes

Table 3-4 shows the degree of consistency between genders for each theme. Themes were given a rating of 4 if they were scored as high frequency, high importance by the relevant gender; 3 if they were scored as high frequency, lower importance; 2 if they were scored lower frequency, high importance; 1 if they were scored lower frequency, lower importance; and 0 if the theme was not elicited at all from that gender. This analysis suggests that there was consistency across genders for most of the nine themes with the highest Relevance Indices.

Diesel vehicle users

Table 3-3 shows the themes elicited from the diesel vehicle users, examples of the constructs assigned to each theme, and their frequency weights, importance weights and Relevance Indices. The themes are listed in order of Relevance Index. There were similarities with themes elicited from gasoline vehicle users, but some important differences. The highest-ranked themes were: *Responsiveness*; *Smoothness*; *Comfort*; *Speed*; *Overall Acceleration*; *Low Noise*; and *Power*. All the other themes had Relevance Indices below the median value of RI.

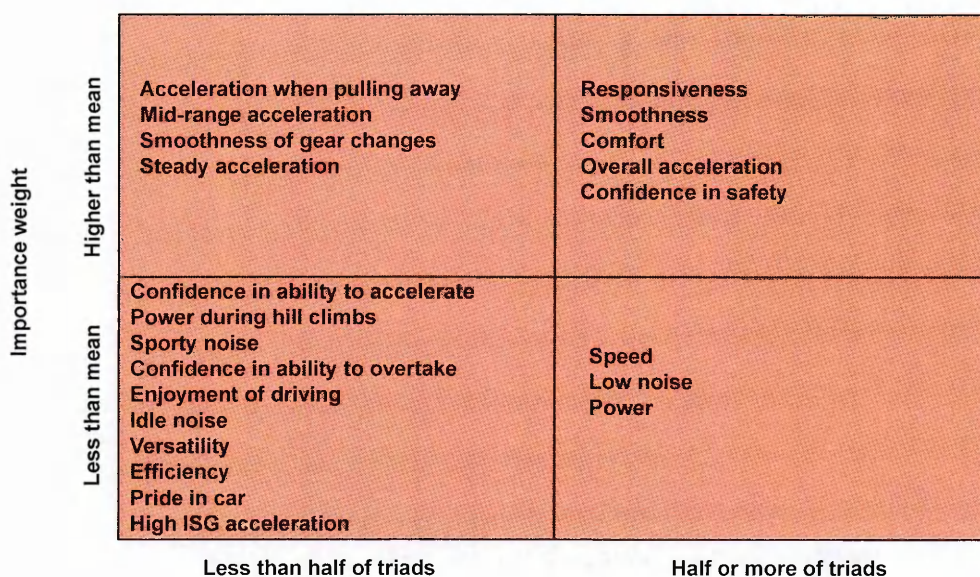


Figure 3-2. Diesel users’ construal of performance: Summary of themes

Figure 3-2 shows these themes organised in terms of frequency weight and importance weight. Table 3-5 shows the degree of consistency between genders for each theme (using the same scheme as Table 3-4). Among the themes with high Relevance Index, *Responsiveness*, *Smoothness*, *Comfort*, *Speed*, and *Confidence in Safety* were consistent across gender. There were substantial gender differences, however, with some themes. *Overall Acceleration* and *Power* were elicited in all four male groups, but only two female groups; and *Sporty Noise* was elicited in three of the male groups but none of the female groups. On the other hand, *Low Noise* was elicited predominantly in female groups (all four, compared with two of the male groups). *Smoothness of Gear Changes* was elicited only from two female groups.

Cluster analyses

Figure 3-3 shows the cluster analysis dendrogram of the grid elicited from a male diesel vehicle user. Two clusters of constructs can be distinguished: the top two constructs, *Quiet - Noisy* and *Smooth running - Rough*, clustered closely together and were distinct from another cluster which included the constructs *Highly responsive - Sluggish*; *Lots of fun - Boring*; *Fast acceleration -*

Feeble acceleration; High top speed - Slow top speed; High pulling power - Low power; and High torque - Low torque. Two additional constructs, *Powerful noise - "Wimpish" noise* and *Low efficiency - High efficiency*, were associated with this cluster, but with lower similarity coefficients (90 versus 94). The first and second clusters had high internal similarity coefficients (0.94) but had lower similarity to each other (coefficient 0.80).

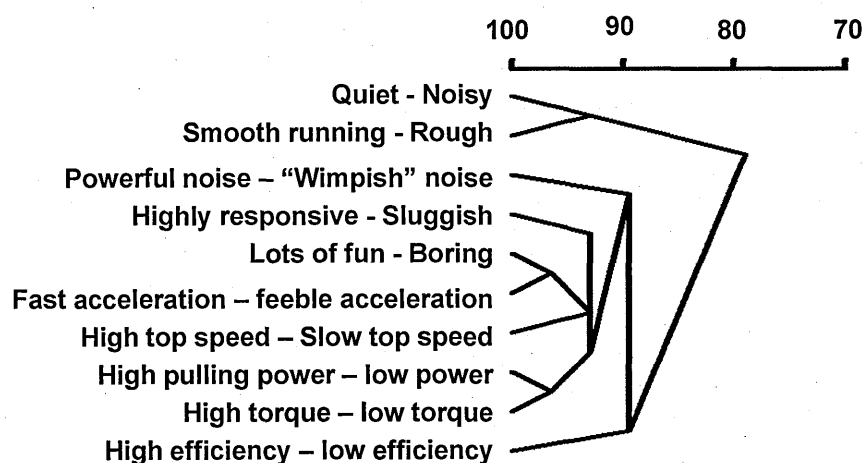


Figure 3-3. Example cluster analysis dendrogram for male diesel vehicle user

A similar cluster structure was observed from most diesel vehicle users. Two clusters could be discerned, one containing constructs relating to the themes *Responsiveness, Power, Speed, Overall Acceleration, Sporty Noise, and Power during hill climbs*, and another containing constructs mainly relating to the themes *Smoothness, Comfort and Low Noise*. This pattern was common to both the male and female diesel vehicle users.

Among gasoline vehicle users, a slightly different pattern emerged. Themes associated with “confidence”, particularly *Confidence in ability to overtake*, were sometimes used together with the themes connected with acceleration, pulling way, power and responsiveness, but were treated somewhat differently by some participants, leading to the cluster structure shown in Figure 3-4. This three-cluster pattern was common to both the male and female gasoline vehicle users.

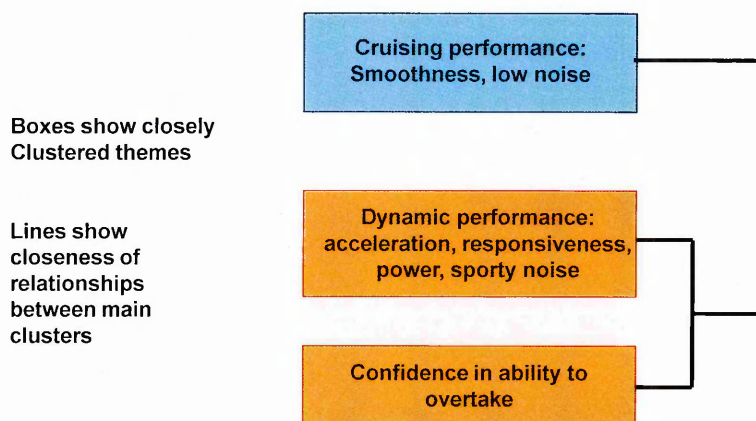


Figure 3-4. Summary of cluster structure for gasoline vehicle users

Summary: a model of how drivers construe vehicle performance

The findings are summarized in a conceptual model of how performance-oriented drivers construe vehicle performance, shown in Figure 3-5. The model draws on the construals of both gasoline and diesel users. It has several key features.

Firstly, drivers construe the performance of their vehicles in terms of two main dimensions: dynamic performance, which refers to performance in those situations where the driver takes control actions using the accelerator pedal that alter the velocity of the vehicle (including maintaining constant speed uphill); and cruising performance, which refers to performance in the situation where the driver maintains constant high velocity, for instance on a freeway/motorway. These dimensions are independent of each other. A vehicle might be perceived as having good dynamic performance but poor cruising performance; or vice-versa; or having both good dynamic performance and good cruising performance; or neither.

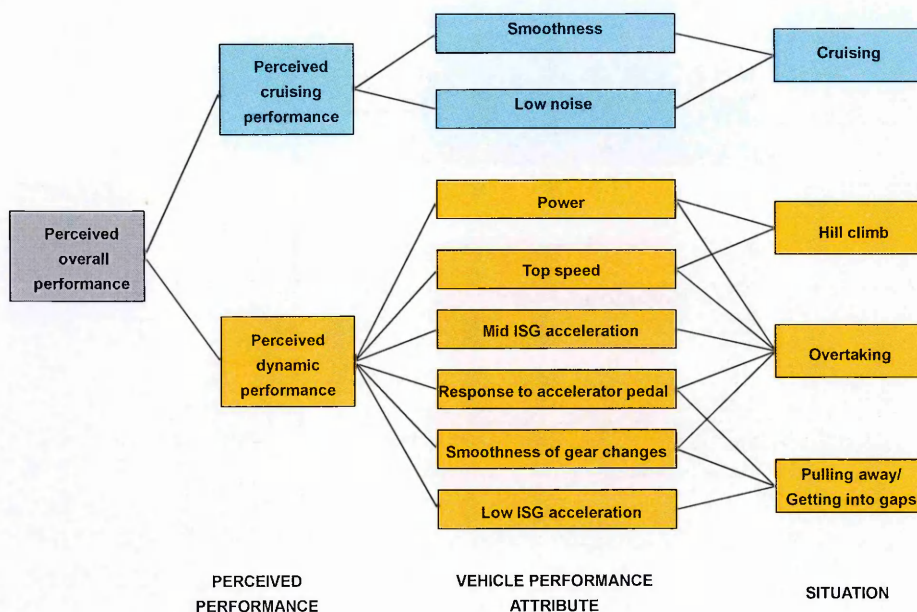


Figure 3-5. Conceptual model of how drivers construe vehicle performance (ISG = Initial Speed and Gear)

Secondly, each of these dimensions is constituted from several attributes. For dynamic performance these are low initial speed and gear (ISG) acceleration and mid-ISG acceleration; response to the accelerator pedal; power; smoothness of gear changes; and top speed. Most of these are closely related, so an improvement in one may tend to result in perceived improvements in the others. For cruising performance, they are smoothness, low noise and comfort. Again these are closely related.

Thirdly, the various attributes of dynamic and cruising performance are not construed in the abstract, but are experienced and construed as relating to specific driving situations. Thus acceleration in low initial speed and gear is construed in relation to situations such as pulling away, and rapid accelerations to get into gaps in traffic. Responsiveness is construed particularly in relation to getting into gaps in traffic. Mid-ISG acceleration is construed particularly in relation to overtaking (typically on single-carriageway roads). Power is frequently used as a synonym for acceleration; but it is also construed as having a particular meaning in relation to the ability to maintain speed on steep or long hills.

Discussion

Cruising and Dynamic performance

The key finding of Study 1 is that drivers construe vehicle performance in terms of two independent dimensions, dynamic and cruising performance. In dynamic performance the driver is actively engaged in changing the state of motion of the vehicle, using the accelerator; in cruising performance the driver is maintaining the state of motion of the vehicle, keeping the accelerator position approximately constant.

One way to interpret this is to consider the driver's level of task engagement in dynamic versus steady-state driving. In dynamic situations the driver's level of engagement with the task of driving is high: it requires attention and imposes cognitive load. The dynamic performance of the vehicle plays an important role in achieving immediate goals and driving tasks. In steady-state driving situations, the driver's level of engagement with driving is likely to be lower: it requires less attention, and cognitive capacity is more available for other tasks. The relevance of smoothness, low noise and comfort may be related to a preference for minimum intrusion of vehicle-related perceptions when the driver is attending to other tasks. There is evidence that drivers do differ in their level of task engagement depending on the driving situation. For instance Harms (1991) found that drivers asked to perform secondary calculation tasks while driving through villages, on rural roads and through rural junctions, performed worse on the secondary task (indicating higher cognitive load) in the more complex situations. Ayama, Hasegawa, Kawaguchi, Ihata, Ikegami, and Kasuga (2002) obtained similar results in a simulator study comparing driving in residential areas and through woods. One might speculate that drivers are motivated to relax as well as disengage when cruising, so that smoothness, low noise and comfort might be associated with relaxation, whereas roughness and loudness might be associated with driving stress.

Situational specificity

An important aspect of the findings was the situational specificity of many of the themes. Participants tended to construe vehicle performance very much in terms of a limited number of specific driving situations in which it was salient to them. Also, different aspects of performance

tended to be salient in different situations. The key situations were pulling away (low-ISG acceleration); overtaking (mid-ISG acceleration, confidence in ability to overtake); hill climbs (power); and cruising (smoothness, low noise). This pattern was similar for both gasoline and diesel vehicle users, but among diesel vehicle users, there was less emphasis on specific situations, with more constructs being expressed in general terms and less in situation-specific terms. It may be that this is related to the lower emphasis that diesel vehicle users placed on dynamic performance (and a desire, evident in the initial discussions with diesel users, to identify themselves as more sensible and contrast themselves with “boy racers”).

Confidence: implicit learning of performance?

The themes *Confidence in ability to overtake* and *Confidence in Safety* did not focus directly on aspects of performance, but rather on participants’ “confidence” in performance. These themes relate to an evaluation by the driver, in which he/she makes an assessment of his/her ability to complete a manoeuvre, and, on the basis of the assessment, arrives at a level of confidence related to that manoeuvre. In this process, prior perception of vehicle performance contributes *indirectly* to the evaluation and to the “confidence” construct, through learning processes.

Consider a situation where a driver is motivated to overtake a leading vehicle, on a road where various potential overtaking opportunities occur, with different levels of task difficulty: for example, a rural single carriageway road with bends and oncoming traffic. Each time a potential opportunity occurs, the driver evaluates it; some opportunities will not be taken, some will. In the evaluation process the driver accesses an internal representation or model of the vehicle’s performance, comparing it with the available opportunity. It is not the vehicle’s actual performance during the manoeuvre that is being evaluated (the manoeuvre has not yet happened) but rather the driver’s pre-existing mental model of it. What the driver experiences is not the performance directly, but the result of the evaluation, expressed as a degree of confidence in ability to complete the manoeuvre.

The mental model that the driver accesses must represent a set of relationships, such as the relationship between a control action (accelerator pedal depression) and its result (vehicle acceleration) in different gears at different initial speeds, and how that is affected by gradients, how the vehicle is loaded, etc. These relationships must be learnt from prior direct perceptions of vehicle performance. However it is not necessarily the case that this learning is experienced explicitly (i.e. the driver is consciously aware of it happening). The mental model may be acquired, and kept updated, through implicit learning processes, outside conscious awareness (Berry, 1997; Reber, 1993; Reed, McLeod, & Dienes, 2010). This will be explored experimentally in Chapter Seven.

Sensory experiences of performance

Perhaps surprisingly, little was elicited in terms of how participants physically experienced aspects of performance. Constructs referred to “acceleration”, rather than to sensory experiences such as being pushed back into the seat, or seeing objects ahead approaching faster, etc. Although participants might have been using “acceleration” as a summary term that included such experiences, there was no evidence for this in the data. It may be that such cues are processed non-consciously (Lewis-Evans & Charlton, 2006), and are implicit in the verbalised construct “acceleration”. The experience of sounds was an exception, where two themes emerged, “Low noise when cruising” and “Sporty noise”. Examination of the constructs themselves revealed a rich lexicon of metaphors for engine and vehicle sounds, such as “industrial”, “purring”, “exciting”, and “comfortable”. This suggests that sound may be an important contributor to drivers’ constructions of vehicle performance.

Implications for low-carbon vehicles with electric and hybrid powertrains

Previous research (e.g. Bunch, Bradley, Golob, Kitamura, & Occhiuzzo, 1993; Lane, 2011) has suggested a public perception that EVs offer lower performance (top speed, and acceleration) than ICE cars. This was reiterated by some participants in the study by Burgess, King, Harris, and Lewis (2013) of meanings attributed to EVs in interactions between EV trial participants and their social contacts: “they’re very slow, like golf buggies, things like that, a milk float” (p. 37). Similarly, the

theme *Vehicle confidence* identified in the qualitative study by Graham-Rowe et al. (2012) into how mainstream drivers experienced the use of a BEV or PHEV, drew on drivers' perceptions that "power and performance was substandard" (p.145). This all suggests that EV performance is currently viewed negatively by drivers, whether or not they have direct experience of EVs. On the other hand some of Burgess et al.'s participants reported that other people had been impressed by the speed, acceleration and low noise of their EVs, while Grahame-Rowe et al. found that participants viewed EVs as a work in progress, and expected performance to improve in the near future.

The emphasis in this literature has been on dynamic performance. Study 1 enriches the picture by finding that cruising performance is also important to drivers, and is construed independently. Electric vehicles have the potential to offer significantly better cruising performance than ICE vehicles. Furthermore, the dynamic performance of EVs available at the time of writing is significantly better than that of the vehicles used by Graham-Rowe et al. EVs could potentially offer better performance in both key dimensions, reversing the perceptions outlined above.

Battery Electric Vehicles

Driving under electric power in a modern BEV can offer higher low-end torque, yielding faster acceleration at low speeds; and increased smoothness and quietness at all speeds, compared with an ICE vehicle. Thus they have the potential to be experienced as better-performing by drivers in terms of both dynamic and cruising performance. We might expect current gasoline vehicle users to place relatively more emphasis on the dynamic performance benefits, and current diesel vehicle users to place relatively more emphasis on the cruising performance benefits.

PHEVs and E-REVs

The implications for PHEVs and E-REVs depend on the powertrain architecture. The advantages outlined in the previous section will apply in full to E-REVs with series architecture (i.e. where the electric motor provides the motive power directly, with the ICE acting as a generator to supply the electricity demand of the motor). The range extender adds a weight penalty that could limit dynamic performance, but this could in principle be offset by a smaller (and less heavy) battery

compared with a similar-sized BEV: the overall impact on the performance experienced by the driver being determined by the design trade-offs of the particular vehicle architecture.

In a PHEV with a parallel powertrain architecture, motive power in some circumstances (typically when substantial acceleration is demanded) is achieved by “blending”, in which both the electric motor and ICE contribute simultaneously. Thus the potential for performance benefits conferred by the electric powertrain may be lower in a parallel-architecture PHEV. In a PHEV, however, the range and recharge-time disutilities are less significant, so potentially could be offset by more modest performance benefits, perhaps confined to dynamic performance in lower speed ranges.

The symbolic role of EV performance

At present, using an EV appears to symbolise openness to ideas, pro-environmental and pro-social values (Burgess et al., 2013; Graham-Rowe et al. 2012; Heffner, Kurani, & Turrentine, 2007; Schuitema, Anable, Skippon, & Kinnear, 2013); and the five-factor traits openness, conscientiousness and agreeableness (Skippon & Garwood, 2011). Good cruising performance is consistent with this symbolism. Being perceived as having better dynamic performance than an ICE may, however begin to widen the range of symbolic meanings that an EV can have. I shall return to this in Chapter Eleven.

Observations on methodology

One reason to use the repertory grid method was to provide a structured approach to eliciting how drivers construe vehicle performance, which could provide insight into relationships between constructs through the ability to use cluster analysis. The cluster analysis revealed two broad structural aspects: the separate clustering of dynamic and cruising aspects of performance, and the distinction between direct perception in the moment, and (possibly implicit) learning of performance. Beyond that, the cluster analysis showed how closely related many constructs were, particularly those related to dynamic aspects of performance. It was perhaps disappointing that a more resolved picture did not emerge; but it seems clear that the intermixed clustering reflected the reality of participants’ use of constructs. General qualitative elicitation techniques (e.g. group

discussion, semi-structured interviews, or projective methods (Birn, 2002, Gordon & Langmaid, 1988)) do not offer this kind of analysis of the relationships between constructs elicited.

The development of grids as a collective endeavour by triads of participants, discussing and negotiating the meaning of each construct, appeared to succeed as a means of eliciting construct definitions that represented common understandings rather than idiosyncratic individual constructs. There were few cases where there was disagreement over meaning within a triad that resulted in individual constructs being recorded.

One issue in qualitative research concerns sample size. Since the goal is exploratory elicitation, there is no requirement that the sample be representative, nor is there a requirement for a particular statistical power. However it is important to establish an appropriate sample that enables elicitation of as much material as possible. Strauss and Corbin (1998) use the concept of *saturation*, which refers to the point at which further interviews or groups do not produce new material. Among gasoline vehicle users, only 5 of 19 themes were elicited from five or more triads; whereas 8 were elicited in only one or two. Among diesel vehicle users, only 8 of 22 themes were elicited from five or more triads; whereas 12 were elicited in only one or two. This is good evidence that saturation of themes that drivers have in common was achieved in this study.

No qualitative research is immune to researcher subjectivity, so it is appropriate to consider reflexively how my background as the researcher may have influenced interpretation of the findings. I am not a performance-oriented driver, and tend myself to attach more value to cruising performance than to dynamic performance, so I may have unwittingly emphasised its importance to others. After initial negative experiences of the performance of older BEVs, I have since had positive experiences of performance when driving a range of modern BEVs, PHEVs and E-REVs. The repertory grid method has less room for subjective interpretation by the researcher than other qualitative methods, so I hope to have avoided significant interpretive biases, by seeking to be led by the data.

There are two limitations to the extent to which the findings of Study 1 can be generalised. Firstly, it was carried out with UK drivers only. Given cultural differences and variations in driving

environments, it seems reasonable to expect that there might be differences in the way drivers in other geographies construe vehicle performance. Secondly, the study was carried out with performance-oriented drivers, so it cannot necessarily be assumed that drivers with less interest in performance will construe it in the same way. It would be interesting to explore, for instance, whether the relative importance of dynamic versus cruising performance varies between cultures and between performance-oriented drivers and others.

Conclusions

Drivers themselves construe vehicle performance as having two independent dimensions, dynamic performance and cruising performance, both of which are situationally dependent. Electric vehicles have the potential to perform better than ICE vehicles in both respects, so this advantage may to some extent offset the reduced utility of low range, long recharge times and higher costs.

Acknowledgments

Fieldwork for 12 of the 16 triads was carried out by staff of the research agency Thinktank. The author designed the study, the procedure, the discussion guide and the materials; led four of the triads; trained the agency staff in repertory grid elicitation; and conducted the analyses.

Material from Chapters Two and Three has been published in a journal article (Skippon, 2014).

Chapter Four. Perception of acceleration: literature and theory

Existing electric powertrains can clearly deliver better cruising performance (smoothness and low noise) than ICE powertrains. They also have the potential to deliver better dynamic performance, but, as discussed previously, such benefits must be traded off against range and recharge time restrictions. It therefore becomes important for the vehicle designer to know how much extra dynamic performance to provide: enough to be perceived as better by a majority of drivers, but not so much more that all-electric range is unnecessarily restricted. Accordingly I now focus on how drivers perceive dynamic performance, and in particular on the perception of differences in vehicle acceleration.

I shall begin by outlining major theoretical approaches to perception, then review the perception of speed and acceleration in driving. I shall then develop a model for the perception of the *maximum* acceleration available from a vehicle. To do this I shall need to consider how different driving behaviours afford different opportunities to perceive maximum available vehicle acceleration.

Perception: a general overview

It is not necessarily the case that a driver will be able to perceive a difference in acceleration just because a difference can be measured in an objective physical test. There are biological constraints on human sensory systems, perceptual systems, and awareness that limit what differences can be perceived, consciously or non-consciously. This and the following sections consider the perception of acceleration from this perspective. The discussion begins with a brief general overview of perception, which will be based largely on vision. Later sections then briefly outline the other main human sensory systems, and the ways that cues from these different systems are combined. Two examples of perception in driving are then discussed: speed and acceleration. Finally, a model is developed of the factors influencing the perception of available vehicle acceleration in naturalistic driving.

Perception is the process of constructing a mental representation of the external world, based on information received via the senses. The term *sensation* is used to refer to the ability of the sense organs to detect various forms of energy in the external world (such as light or sound waves). The term *perception* is used to refer to the process of constructing a mental representation of the external world using information contained in that energy (Goldstein, 2001; Palmer, 1999; Pike & Edgar, 2005; Sekuler & Blake, 2002; Styles, 2005). For instance, sensation refers to the signals from photoreceptors in the eye reacting to light impinging on them; perception refers to the person seeing that there is a red car ahead on the road.

Visual perception is arguably the most important modality in driving (Cavallo & Cohen, 2001; Groeger, 2000; but see also Sivak, 1996). Some processing of visual information takes place directly at the retinae (Halliday, 1992; Palmer, 1999). For instance, a degree of spatial information is encoded by ganglion cells, which typically receive inputs from around 100 photoreceptors in primates, and have circular receptive fields consisting of concentric antagonistic regions that detect luminance discontinuities. Retinal output thus contains some preliminary edge-detection information as well as colour and luminance information. Output from the retinae goes via the optic nerves to the lateral geniculate nuclei (LGN) of the thalamus, where further processing takes place, and thence to the primary visual cortex, area V1. Input from the nasal half of each retina crosses to the LGN in the opposite brain hemisphere, whilst input from the temporal half reaches the ipsilateral LGN so that each side of the visual cortex receives input from only the opposite side of the visual field. Further visual processing involves a series of cortical areas in the occipital lobe known as V2 to V5, and in the middle temporal area, MT (Palmer, 1999).

Information from the visual cortex appears to follow two separate pathways, the ventral stream which projects to the inferotemporal cortex, involved in object recognition, and the dorsal stream which projects to the parietal cortex, involved in processing the spatial relationships and movements of objects (Goodale & Milner, 1992; Palmer, 1999). Bridgeman (1992), Neisser (1994), and Norman (2001, 2002) have proposed dual-process models in which the ventral stream is concerned with “perception for recognition” and the dorsal stream is concerned with “perception

for action". The two streams, are, however, interconnected, and converge in the prefrontal cortex (Rao, Rainer, & Miller, 1997).

There are many approaches to understanding the processes involved in the transition from sensation of light energy to visual perception. There is not space to review them in detail here, but I shall attempt to illustrate some key ideas by outlining three approaches: ecological, computational and statistical.

The ecological approach was based on the premise that the information available from the visual environment is so rich that no cognitive processing is required at all (Gibson, 1950, 1966, 1979). It has largely been superseded by the other approaches, but I include a brief discussion here as some of its concepts are drawn on in the driving perception literature. Gibson developed the theory from work on training pilots to land. He found that tests based on pictorial stimuli did not predict pilots' performance, and concluded that much more information was available, and used, in real world images. In Gibson's theory, action rather than mental representation is the end point of perception: so the theory primarily relates to only one of the two processes in dual-process theories.

In Gibson's theory, light reflected from textured surfaces in the external world acquires structure through its interaction with those surfaces, which is then encoded in the *ambient optic array*, the pattern of light impinging on the observer's retinae. The optic array contains features called *invariants* that provide unambiguous information about the external world. An example is the texture gradient, in which, since the density of texture elements on a surface is constant, any change in the apparent density in the image must indicate motion towards or away from the observer. Movement or flow in the optic array also contains information about the position, shape and state of motion of objects in the external world, encoded, for instance, in the angular position and size of their textured surfaces.

Rather more controversially, Gibson proposed that features of objects in the external world provide direct *affordances*, i.e. they contain information on their own use sufficient for the perceptual system to use to direct action, without the need for cognitive processing of images. Most cognitive psychologists and cognitive neuroscientists would not accept this, because of accumulated evidence

that cognitive processing does occur (Palmer, 1999). However Gibson's critique of the information poverty in laboratory stimuli is particularly relevant when considering driving simulation, a research tool I shall apply in this thesis.

A contrasting approach is to see visual perception as a bottom-up computational information processing problem, in which information from the incoming optical array is processed through a series of stages, each of which generates an increasingly sophisticated representation (Marr, 1982). I shall illustrate this approach using Marr's theory, recognizing that the approach, but not necessarily the detail, remains widely accepted (Wade & Bruce, 2001). The first stage in Marr's theory involves the production of a grey-level description, based on the pattern of activation of retinal cells. This is then processed into a raw primal sketch by a process of Gaussian blurring and edge detection (Marr & Hildreth, 1980; Glover, Skippon, & Boyle, 1995). Then a full *primal sketch* is constructed, in which the spatial relationships of objects and surfaces are specified by using perceptual organizing principles such as clustering and continuity. Finally, information from additional computational modules such as motion detection is integrated to produce a *2½D sketch* made up of vectors that specify the distance and orientation of visible surfaces, in relation to the observer's position.

Since Marr proposed this computational approach, cognitive neuroscience has refined our understanding of computational processes in the brain. I shall not discuss these developments further here, but shall return to the topic in Chapter Ten.

This kind of bottom-up computational approach, however, still provides an incomplete picture of perception. If objects in the visual field are to be recognized, they must at some stage be compared to stored, prior knowledge of the visual patterns produced by different objects (Rock, 1977, 1983, 1997). Gregory (1980) proposed that this "constructivist" top-down process involves the generation of a series of perceptual hypotheses about what an object might be, which are subject to review as more bottom-up information becomes available. Computational and constructivist approaches are focused on "perception for recognition", the building of a mental representation of the external world, rather than on directing action, and so appear to relate to the opposite function in dual-process models than does the ecological approach. Goodale and Humphrey (1998, 2001) have

proposed that ecological and computational/constructivist approaches may be complementary, rather than competing models, each relating to a different purpose for perception.

Another approach to visual perception is to consider it as a process of statistical inference, using Bayesian methods (Bennett, Hoffman, & Prakash, 1989; Kersten, 1990; Knill & Kersten, 1991; Knill & Richards, 1996). In the Bayesian approach, the perceptual process is characterized in two parts. Firstly, the information about the external world contained in an image is represented as a probability distribution, which describes the relative likelihood that the external world is in different states, given the image data. Secondly, there is an inference process that selects an estimate of the state of the external world, the perception of that state, from among those represented in the probability distribution.

Formally the first stage in the process is expressed as follows:

$$p(S|I) \propto p(I|S)p(S) \quad \dots(4-1)$$

Where $p(S|I)$ is the posterior distribution, the probability that the scene is S , given that the image is I . The term $p(I|S)$ is the likelihood function for S , the probability that a scene S will give rise to an image I . It incorporates a model of the process of image formation, $f(S)$, which includes factors such as light transmission, reflection, perspective, the spectral response of photoreceptors in the retinae, etc. It also includes a model of the image noise, N . Thus:

$$p(I|S) = p(f(S) + N|S) \quad \dots(4-2)$$

The term $p(S)$ is the prior distribution of possible scenes, and contains, for instance, information on the prior probability of different scene properties occurring in the external world. It represents stored knowledge used by the perceptual system, the assumptions about the probability of scenes that the system would make in the absence of any sensory input.

The posterior distribution provides a statistical description of the information content of images. In the second stage of the perceptual process, an inference rule is used to select a perceptual estimate of the scene, from among those represented in the posterior distribution. One example of such an inference rule is the so-called Maximum Likelihood (MAP) estimator (Yuille & Bultoff, 1996)

which simply selects the most probable scene from those in the posterior distribution. More generally the estimator is a loss function, which specifies the penalty paid by the system for producing an incorrect estimate (Sperling & Doshier, 1986). The loss function links the perceptual process to its purpose; in principle, perception for action and perception for recognition might employ different loss functions, to represent different consequences of inaccurate estimates of the scene. In practice many studies default to using MAP estimators, effectively assuming that no differences in value (loss or gain) attach to any particular estimate.

There are other models of visual perception besides those outlined above; the intention here has been merely to give a flavour of some influential approaches that may be drawn on later. The Bayesian approach, in particular, is useful when we consider perception involving the combination of cues from multiple sensory modalities.

Non-visual human senses relevant to perception in driving

Although vision is clearly central to perception in driving, other modalities also contribute. The most relevant are the auditory, vestibular and cutaneous systems. These are outlined briefly here.

Having two ears, one on either side of the head, confers a degree of redundancy, and a capacity for perceiving the direction of incoming sounds, by comparing the arrival time or phase of sounds at each ear. The outer ear and middle ear provide transfer of external sound wave energy to the tympanum (“eardrum”), a membrane which couples the energy to the liquid-filled cochlea or inner ear (Halliday, 1992). Auditory hair cells in the cochlea generate signals in response to sound wave energy in the cochlear fluid. Hair cells have specific, narrow frequency responses, each acting as a band-pass filter (Moore, 2001). They are organized such that high frequency sounds are detected at the apical end of the cochlea (furthest in from the tympanum) and low frequency sounds are detected at the tympanum end. Signals pass via the cochlear nerve, cochlear nuclei, inferior colliculi and medial geniculate nuclei in the thalamus to the auditory cortex, which has a tonotopic organization, with bands of neurons that are triggered in response to particular frequencies in the incoming sound. This organization enables perception in terms of both loudness and frequency.

Various higher-order processes then gradually elaborate a mental representation of the sound environment (Bregman, 1999; McAdams & Bigand, 1993).

Humans can respond to sound frequencies in the range from approximately 20 Hz to approximately 16 kHz. Sensitivity varies with age and between individuals, with a maximum in adults at around 1 kHz (Moore, 2001).

The auditory system has a very wide dynamic range, so sound pressure levels are typically measured on a logarithmic scale, the decibel scale, on which 0dB is the threshold of human hearing. The loudest tolerable level is around 120dB. When measuring loudness, however, it is necessary to take the frequency distribution within the sound signal into account. Sound pressure measurements are frequency-weighted, in attempts to reproduce the frequency response of the human auditory system. Figure 4-1 shows three frequency weightings commonly used in sound measurement, the dB(A), dB(B), and dB(C) weightings. The dB(A) filter corresponds to the inverse of the 40dB equal-loudness curve for human auditory response. The less commonly used dB(B) and dB(C) curves correspond better to subjective loudness estimates at very high sound pressure levels. Other frequency weightings are optimum in particular circumstances. For example, Ajovalasit and Giacomini (2007, 2009) have shown that for a range of diesel engine idle conditions, the Zwicker loudness weighting (Zwicker, 1977; Zwicker & Fastl, 1990) correlates best with subjective ratings of sound intensity.

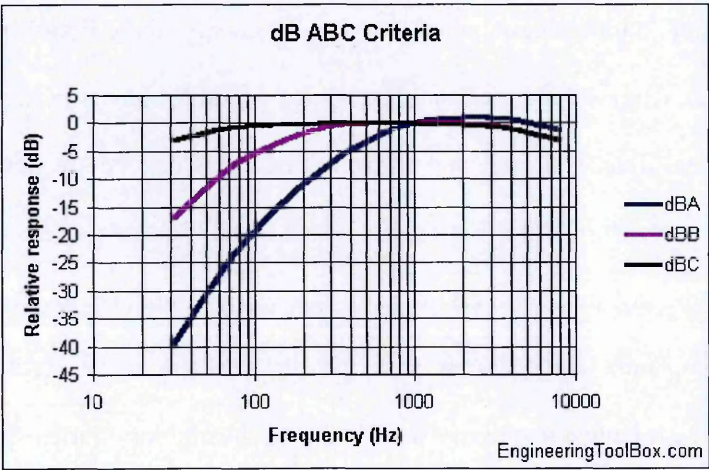


Figure 4-1. Frequency weighting of sound pressure levels

(source: www.EngineeringToolBox.com)

In driving, the sound of the engine can be an important cue to the performance of the vehicle. Conventional internal combustion engines produce sound containing a fundamental frequency (the engine rotation speed), and harmonics of that frequency. The fundamental frequency of an engine idling at 1000 revs per minute is $1000/60$ or 16.7 Hz, close to the lower threshold. This suggests that most of the sound heard at idling is higher harmonics of the fundamental frequency. At higher engine speeds the fundamental component of the engine sound is within the audible range. Typically, engine frequency increases with vehicle speed (depending, of course, on other factors such as the gear ratio, gradient, etc.). Thus drivers can use both the frequency-weighted loudness of the engine sound, and its fundamental frequency, as cues. In addition, there are sound components from the contact of the tyres with the road, and the aerodynamic drag as the vehicle displaces air from its path. Both of these increase in intensity with speed, but unlike the engine sound, they are independent of engine frequency.

The associations between engine loudness and frequency, and driving speed or acceleration, are learned associations: drivers develop representations of them as they experience driving (or being driven). It is possible that drivers can learn new associations as they experience, say, different vehicles, or driving with different fuels¹¹. In this sense they are quite different from the visual mechanisms of speed perception.

One additional sensory modality is particularly relevant to the perception of vehicle performance – the sensing of pressure and vibration by cutaneous mechanoreceptors in the skin. For reasons of space I shall not describe this system at length; readers are referred to Boff and Lincoln (1988) and Goldstein (2001) for details. In driving, two classes of mechanical cue are particularly relevant: pressure, especially on the back, as a cue for acceleration; and vibration, sensed particularly through the hands, feet, and seat. Women generally have lower thresholds for pressure sensations than men (Weinstein, 1968). Gender differences in response to steering wheel vibration have been

¹¹ For instance, when running on a fuel which delivers higher power per engine cycle (e.g. because of higher energy density), an internal combustion engine can deliver the same output at lower engine speed, affecting the pitch of the engine sound.

reported by Jeon, Ajovalasit, and Giacomini (2009). Thresholds for detecting vibration in the fingertips are lowest at frequencies in the range around 200 to 400 Hz (Boff & Lincoln, 1988). Thresholds are higher over the range of engine frequencies normally experienced in driving.

Finally I consider the vestibular system. Unlike the visual, auditory and cutaneous systems, it does not provide information about the state of the external world, but rather it provides signals relating to the movement and orientation of the head (Boff & Lincoln, 1988). There are vestibular organs in both inner ears. Each comprises three orthogonal semi-circular canals, which sense rotational accelerations of the head in three dimensions, and two otolith organs, which sense the direction and magnitude of gravito-inertial force.

Although it is difficult to isolate experimentally (Seidman, Telford, & Paige, 1998), the otolith signal is ambiguous, since the same signal can be generated by linear acceleration, head tilt, or a combination of both. The otolith organs provide a signal reporting the direction of the force of gravity in head-centred co-ordinates. In the absence of linear acceleration, this indicates the orientation of the head. In the presence of linear acceleration, the otolith signal corresponds to the resultant of the gravitational and inertial acceleration vectors, and because of the equivalence principle (Einstein, 1907) these cannot be disambiguated. Thus in the absence of other cues (such as a visual horizon), forward acceleration is interpreted as the head being tilted backwards, and backward acceleration is interpreted as the head being tilted forwards. In the presence of a visual horizon, however, the otolith signal provides a perception of linear acceleration (MacNeilage, Banks, Berger, & Bulthoff, 2007; Seidman et al., 1998). This ambiguity between tilt and linear acceleration can be exploited in the design of motion cueing systems for vehicle simulators, a topic to which I shall return later.

Combining perceptual cues

Given that information concerning an aspect of the external environment (such as vehicle performance) can be encoded in several different modalities, or different cues in the same modality, it is important to understand how these cues are combined to provide an integrated percept.

One theoretical approach to cue combination is to assume that cues are combined as weighted averages (Bruno & Cutting, 1988; Doshier, Sperling, & Wurst, 1986; Maloney & Landy, 1989; Zupan, Merfeld, & Darlot, 2002) with the weight W_j given to the j^{th} cue (of J) being determined by its reliability (signal-to-noise ratio or variance σ_j^2):

$$W_j = \frac{1/\sigma_j^2}{\sum_{j=1}^J (1/\sigma_j^2)} \quad \dots(4-3)$$

Implicit in this approach is the assumption that the cues are weakly coupled, i.e. processed independently of each other. There is empirical support for this where the cues depend on different sensory modalities.

Bayesian models take into account not just the sensory cues, but also priors, which represent stored knowledge of the possible distributions of states of the external world. If the sensory cues are weakly coupled, and the likelihood functions are Gaussian, Bayesian approaches also yield a weighted average (Ernst & Banks, 2002; Ghahramani, Wolpert, & Jordan, 1997), but one that also includes the prior. Priors generally have less reliability and hence lower weights than sensory likelihood functions, but nevertheless have an impact on the perceptual estimate when sensory inputs are unreliable. Ernst and Banks (2002) showed that such a model predicts the way that visual and haptic (touch) cues are combined to judge the size of an object. MacNeilage et al. (2007) found that a similar model predicts the way visual and vestibular cues combine in the perception of linear acceleration and tilt.

However the assumption of weak coupling is less obviously valid when there are multiple cues from the same modality, for instance perception of speed from engine loudness and frequency, or perception of acceleration from optic flow of texture elements, and rate of increase in angular size of an object ahead. Yuille and Bulthoff (1996) have used a Bayesian approach to such cases, which stresses the need to take into account the prior assumptions used in processing the cues together.

Consider a case where there are two sources of speed estimate, x and y , from visual scene information. In the weighted-average model there would be two estimates of speed, S_x and S_y , with weights W_x and W_y , yielding a combined estimate \hat{S} :

$$\hat{S} = W_x S_x + W_y S_y \quad \dots(4-4)$$

Yuille and Bulthoff (1996) and Bennett, Hoffman, Prakash, and Richman (1996) have shown that equation (4-4), the weak-coupling case, can be derived using the Bayesian formulation, modelling the weak coupling by multiplying the posterior distributions:

$$p(S|x, y) = p_x(S|x)p_y(S|y) \quad \dots(4-5)$$

First-order perturbation theory can then be used to find the resulting MAP estimate (which is a weighted average). This is the approach used, for example, by Ernst and Banks (2002) and MacNeilage et al. (2007).

However if the two cues are coupled (so that processing of one influences processing of the other) then we cannot assume that prior assumptions used in processing are independent (Yuille & Bulthoff, 1996). Instead we specify a combined likelihood function $p(x, y|S)$ for the two cues, and a single prior assumption $p(S)$ for the combined system:

$$p(S|x, y) = \frac{p(x, y|S)p(S)}{p(x, y)} \quad \dots(4-6)$$

This will not generally reduce to $p_x(S|x)p_y(S|y)$. Yuille and Bulthoff (1996) give examples from visual processing of shape (from shading and texture) and position (from stereo viewing and controlled motion) that support the Bayesian model with strong coupling.

Cues from different modalities (using different perceptual systems) are independent (Yuille & Bulthoff, 1996), and so can be combined as weighted averages, while cues from the same modality may be coupled, and require a more complex Bayesian analysis.

There are other, non-Bayesian models of cue combination. That of Reymond, Droulez, and Kemeny (2002) is of particular interest in that it underlies the approach to motion simulation in the Renault driving simulator (Reymond & Kemeny, 2000). Their approach is to calculate cost functions for each sensory estimate based on two contributions: measure constraints (based on the internal model of the sensor's transfer function) and coherence constraints (internal models of how the various perceptual estimates should relate to each other: for instance that, in the absence of

centripetal forces, the linear acceleration estimate should be the derivative of the linear velocity estimate). Simultaneous minimization of the cost functions for each sensory modality yield a set of estimates of the percept. This is a fruitful approach that agrees with various experimental data, though MacNeilage et al. (2007) comment that it is unclear whether it can find optimal solutions given the relative uncertainties in multi-sensory signals.

Perception of speed in driving

This section outlines an example of perception in driving that illustrates how the theoretical approaches I have described can be applied: the perception of speed. Speed perception is, of course, involved in controlling the vehicle, and in this sense it can be seen as an example of perception for action.

Consider first the visual perception of speed. In Marr's computational theory of visual perception, motion is processed by motion detection modules whose output is integrated with the primal sketch to produce the 2½D sketch. Motion detectors have been identified in the brain (Newsome, Shadlen, Zohary, Britten, & Movshon, 1995), and are known to process both speed and direction information. Area V5 (or MT⁺) contains motion sensitive neurons that are tuned to specific speeds (Born & Bradley, 2005; Groh, Born, & Newsome, 1997; Lisberger, Morris, & Tychsen, 1987; Liu & Newsome, 2005; Newsome & Pare, 1988; Nichols & Newsome, 2002). Each such neuron has a peak firing rate in response to a particular speed of motion in its receptive field (area on the retina), and a narrow band-pass so that it does not respond to speeds above or below its tuning peak. Thus the pattern of activation in the neuronal population in MT forms a representation of the distribution of speed in the image (Price, Ono, Mustari, & Ibbotson, 2005).

Neurons in the visual system show the phenomenon of adaptation, a reduction in firing rate over time in the presence of a constant stimulus. This has been shown for neurons involved in motion detection (Clifford & Ibbotson, 2002). This suggests that a constant speed of movement in the visual field will be perceived as a gradual slowing, and this has indeed been found in psychophysical tests (Goldstein, 1957; Thompson, 1981). The amount of the reduction in perceived speed declines exponentially with time (Bex, Bedington, & Hammett, 1999; Clifford & Langley,

1996; Goldstein, 1957; Hammett, Thompson, & Bedingham, 2000). The adaptation appears to be associated with an increase in sensitivity to speed changes (Bex et al., 1999; Clifford & Langley, 1996; Clifford & Wenderoth, 1999; Krekelberg, van Wezel, & Albright, 2006). Heitanen, Crowder, and Ibbotson (2008) found a more complex picture in which, while adaptation at high speeds and testing at low speeds produced a reduction in perceived speeds (relative to veridical speed), adaptation at low speeds and testing at high speeds produced an increase in perceived speeds.

Several authors have developed Bayesian models of visual speed perception that account for some of these psychophysical results (Ascher & Grzywacz, 2000; Geisler & Kersten, 2003; Stocker & Simoncelli, 2006; Weiss, Simoncelli, & Adelson, 2002). Most of these models assume some form of low-velocity prior, based on the assumption that objects in the environment are more likely to be stationary or moving slowly, than moving quickly. In addition they assume that the perceptual process is noisy. Ascher and Grzywacz's model, for instance, models the motion detectors in MT as a set of spatial frequency and temporal frequency filters, whose outputs are subject to Gaussian noise and are combined, together with a prior that is biased towards low speeds. Their model predicts the effect that low image contrast causes low speeds to be estimated as lower than veridical, and high speeds to be estimated as higher. Hurlimann, Kiper, and Carandini (2002) found agreement between the Bayesian model of Weiss et al. (2002) and their empirical speed estimates with variable contrast, provided that a non-linear model of image contrast was used during model interpretation. However Hammett, Champion, Thompson, and Morland (2006) found that speed perception at low luminance was not consistent with the current Bayesian models, so these models do not yet provide a comprehensive account.

Other analyses of visual perception of speed are based on optic flow (Palmer, 1999, p504; Carvallo & Cohen, 2001). Optic flow can be described by a set of velocity vectors associated with each texture element in the visual field. Global movement of texture elements is indicative of self-motion through the environment. Direction of self-movement can be ascertained by the direction of the focus of expansion of the set of vectors. For instance, in forward motion on the ground, the focus of expansion is a point on the horizon, and all vectors appear to point away from the focus. Speed information is contained in the magnitude of the vectors. Absolute speed, however, cannot

be estimated directly from optic flow, because of a fundamental scaling indeterminacy: the same retinal change could result from a large movement relative to a distant texture element or a small movement relative to a close texture element. Additional prior assumptions, or scale information (such as recognition of objects of familiar size, which yields distance estimates) are needed to resolve the scale indeterminacy (Palmer, 1999).

Brandt, Dichgans, and Koenig (1973) showed that human perception of ego-speed (speed of self-motion) depends on optic flow in the peripheral visual field rather than the centre: a flow stimulus in the central 30° produces virtually no sensation of speed.

The above discussion has outlined visual speed perception in generic visual environments. However, because of its importance in road safety, there have also been a number of applied studies of speed perception specifically in driving. Many of these draw on or illustrate the themes outlined above. For example, Godley, Triggs, and Fildes (2004) attributed reductions in speed by drivers in a driving simulator, in the presence of a hatched marking in the centre of the road, to the markings causing enhanced peripheral visual speed perception.

Different classes of texture elements in the optic flow have been found to produce different perceptions of speed during driving. Denton (1980) projected either textured patterns or transverse strips onto the roadway in a simulator study. Drivers were asked to reduce their speeds by half on entering the test zone; transverse strips produced greater reductions than textured patterns. Such research led to the introduction of transverse strips on approaches to roundabouts in the UK (Denton, 1980) and on highway exits in France (Malterre, 1977). Vertical features also affect speed perception: Manser and Hancock (2007) found that drivers in a simulated tunnel decreased speed in response to a pattern of decreasing-width stripes on the walls, and increased speed in response a pattern of increasing-width stripes. Transverse and vertical visual features are now part of the repertoire of “psychological traffic calming” measures (Kennedy, Gorell, Crinson, Wheeler, & Elliott, 2005). However there is also evidence that drivers who regularly use a particular road section, gradually adapt to the presence of such markings, so that after an initial reduction in mean speeds on introduction, drivers who become familiar with them gradually increase their speeds on subsequent drives (Shinar, Rockwell, & Maleki, 1980).

There is also evidence that drivers adapt to speed itself, in such a way that the sensation of speed reduces with time during extended intervals of constant-speed driving (Irving, 1973; Schmidt & Tiffin, 1967). Recarte and Nunes (1996) found that previous acceleration or deceleration influenced verbal estimates of current speed. However experimental data on both the magnitude of the adaptation and the time for the adaptation to take effect have been inconsistent. For instance, adaptation time was approximately 1 minute in Irving's (1973) study, but over 30 minutes in that by Schmidt and Tiffin (1967).

Researchers have often used a paradigm in which drivers are asked to produce a speed, rather than verbally estimate it: for instance, doubling or halving their current speed (Groeger, Carsten, Blana, & Jamson, 1999; Recarte & Nunes, 1996). In this paradigm speed perception is specifically used to direct action. Typically when drivers are asked to halve their current speed, they do not reduce it sufficiently; whereas when drivers are asked to double their current speed, they do not increase it enough. These results have been interpreted in terms of speed adaptation, which causes the initial speed to be perceived as lower, so that smaller increments of change are required to halve or double it. On a cautionary note Borg (1961) pointed out that in halving and doubling experiments, the time taken to execute a halving or doubling of speed also varies systematically with initial speed, and this may confound these findings. However, the phenomenon of speed adaptation in driving agrees well with the adaptation of neuronal signals outlined above.

Speed perception is also influenced by other, non-visual perceptual cues. In a frequently cited study, Evans (1970) asked participants in the passenger seat of a car to estimate the speed of the car (driven at a range of actual speeds) in normal conditions, or blindfolded, or wearing ear defenders to impair hearing, or both. Speed estimates were higher when blindfolded, but lower when hearing was impaired. These results suggested that sound is used as an additional cue in estimating the speed of self-motion in a car, and in its absence speed was consistently under-estimated. Other authors (Horswill & McKenna, 1999; McLane & Wierwille, 1979; Matthews & Cousins, 1980) have found inconsistent results when asking drivers to make verbal speed estimates with and without auditory attenuation. Triggs and Berenyi (1982) found that auditory masking with 100dB white noise, rather than auditory attenuation, also reduced estimated speeds by 10kph. Horswill and

Plooy (2008a) confirmed the under-estimation effect of attenuation using a robust paired comparison method.

These findings can be interpreted using a Bayesian model of speed perception that includes a prior distribution for speed, which peaks at zero. The prior represents the assumption that in the absence of perceptual information to the contrary, the most likely speed through the environment is zero. In the presence of consistent visual and auditory cues to speed, the prior has relatively little weight. When the auditory cue is attenuated, the reduced loudness represents a sensory cue for lower speed, which will reduce the weighted average. In addition, the reliability of the auditory loudness reduces, so the relative weight of the prior increases, which reduces the overall speed estimate (Horswill & Plooy, 2008a). An interesting parallel to this is the experiment by Horswill and Plooy (2008b) in which speed estimates were lower when image contrast was reduced. The Bayesian interpretation of this finding is that the reduced contrast decreases the reliability of the visual cues, reducing their weight relative to the prior, resulting in under-estimation of speed.

Perception of acceleration in driving

As Study 1 found, acceleration is a key aspect of the way drivers construe dynamic performance. This section considers the perception of acceleration in driving, which has been less thoroughly studied than perception of speed.

How is acceleration decoded from vision? In principle, acceleration information is available from optic flow. In forward self-acceleration, the magnitudes of the velocity vectors associated with texture elements in the expanding flow field increase with time. However, in contrast to speed, Lisberger and Movshon (1999) found that acceleration was not represented directly in the outputs of individual neurons in the MT area of the brains of anesthetized macaque monkeys. Price et al. (2005) extended this finding to conscious macaques. They were able to show, however, that a model in which acceleration and deceleration were represented in the overall pattern of activity of the population of MT speed-tuned neurons could account for several experimental findings. Thus there appears to be a plausible neuronal mechanism for encoding acceleration from vision.

Linear acceleration can also be sensed by the vestibular system. The otoliths indicate the direction and magnitude of the gravito-inertial force relative to head coordinates, while the semicircular canals signal the rotation rate of the head in three dimensions (Reymond et al. 2002; MacNeilage et al., 2007; Seidman et al., 1998). Boff and Lincoln (1998) reviewed psychophysical evidence for human vestibular perceptual thresholds for linear acceleration in various directions relative to the body and to gravity. Most of the thresholds were in the region of 0.06ms^{-2} .

In a study by Travis and Dodge (1927), participants experienced oscillating motion, seated, facing in the direction of motion. The authors reported absolute thresholds for forward linear acceleration of 0.08ms^{-2} when participants were free to move in the seat, and 0.20 to 0.25ms^{-2} when participants were “firmly seated”, unable to move. The difference suggests one threshold when both vestibular and cutaneous information was available, and a higher threshold when only vestibular information was available. It indicates that, in the free-to-move condition, additional cues from pressure of the seat on the body (feeling “pushed into the seat”) led to a substantially lower difference threshold.

MacNeilage et al., (2007), in a careful experiment using simulated motion, measured difference thresholds for acceleration of around 0.18ms^{-2} based on a visual cue only (movement through a simple simulated visual scene consisting of a horizontal horizon and human figures at various apparent distances to give perspective information). Using a combination of visual and motion cueing (using tilt coordination of a motion platform to provide the vestibular cue) the cue-combined difference threshold was 0.14ms^{-2} . In their experiment the standard acceleration (the standard value of stimulus intensity, ϕ) was 0.68ms^{-2} , so these threshold values represented differences of 26.5 % and 20.6% respectively. To put these figures into a driving context, the average acceleration rate of a typical C segment medium family hatchback car (e.g. Ford Focus) with a 1.4 litre engine from 0mph to 60kph is around 2.0ms^{-2} ; and the difference in acceleration rate over this speed range with a more powerful 1.6 litre engine is around 15%. This suggests that drivers should be unable to perceive much difference between the acceleration performances of cars separated by one typical increment of engine size. However it may be that in practice, a richer mix of cues is available, making the threshold lower. MacNeilage et al. found that their findings were in agreement with a Bayesian cue-combination model that assumed conditional independence

of the vestibular and visual signals, and assumed two priors: zero linear acceleration and zero tilt (head upright).

Other, non-directional sensory inputs can also provide acceleration information. Seidman (2008) has shown that vibration and mechanical noise of the apparatus causing the motion can be used as cues for motion. The latter are, of course, particularly important in driving, where noise in particular provides significant additional information on acceleration.

Although there is an extensive literature on the design of motion systems for driving simulators to provide realistic multi-sensory sensations of acceleration (Dagdalen, Reymond, Kemeny, Bordier, & Maizi 2009; Groen & Bles, 2004; Nehaoua, Arioui, Espie, & Mohellebi, 2006; Reymond & Kemeny, 2000; Son, Choi, & Yoon, 2004), the research literature provides relatively little information on perception of acceleration or acceleration differences in driving itself.

Fukuhara, Kamura, and Suetoni (2002) measured participants' evaluations of acceleration differences in a driving simulator. Participants experienced a pair of accelerations, with a standard level of acceleration, equivalent to "the value of 1.8L sedans currently on the market", and one of two comparison levels, 15% higher or 15% lower than the standard, and were asked to rate the difference in acceleration between them. Participants apparently tended to rate the acceleration as higher in the 15% higher acceleration condition, but as no different in the 15% lower condition. This is a difficult result to interpret, as the authors give rather sparse details of the experimental method and no statistical analysis, and the authors offer no explanation for the inconsistency. We might cautiously conclude that the findings indicate a difference threshold somewhere in the range 0-15% for mid-range accelerations.

Zikovitz and Harris (1999) measured the head tilt of drivers negotiating bends in real vehicles equipped with a three-axis accelerometer. In this experimental paradigm, the centripetal forces acting on the head were dependent on speed, but the visual curvature of the road ahead was not, so the vestibular response to centripetal force and the visual response to the scene were uncoupled. Drivers' head movements were correlated with the visual curvature but not with the centripetal force. The authors suggested that this finding supports the use of a predominantly visual reference

frame for the driving task. It is unclear, however, how far findings relating to centripetal accelerations can be generalized to longitudinal accelerations.

Driving behaviour and the opportunities it affords to perceive available vehicle acceleration

Individual differences in driving behaviour will have a significant impact on the actual accelerations that drivers experience, and the opportunity for them to experience the maximum performance available from a vehicle. A driver who infrequently uses full accelerator pedal depression will rarely experience the maximum acceleration available in a particular initial speed and gear condition, whereas a driver who routinely uses full pedal depression will experience it much more often. To fully understand how drivers perceive available vehicle acceleration, we must understand how differences in driving behaviour afford different opportunities to experience it. I begin by considering models of driver behaviour.

Models of driver behaviour

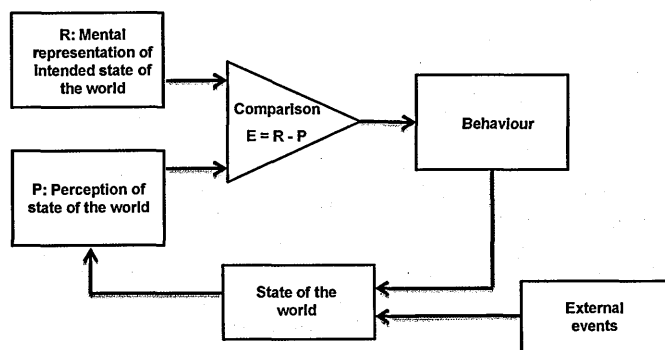


Figure 4-2. Self-regulation of behaviour in the pursuit of a goal, through feedback control

Wilde's (1982) Risk Homeostasis Theory (RHT) proposed that drivers have an (individually defined) level of "target risk", and adapt their driving behaviour in response to changes in the driving environment in order to maintain a constant risk level. RHT is an example of a *self-*

regulation model in which behaviour is controlled, through a feedback process, in the pursuit of a target reference state or “goal” (Carver & Scheier, 1998; Miller, Galanter, & Pribram, 1960; Powers, 2005). Figure 4-2 illustrates feedback control.

In self-regulated goal pursuit, a person carries out behaviour in order to change his/her current perception of some aspect of state of the world, **P**, so that it matches as closely as possible an intended state of the world, or “reference state”, **R**, that is represented in her/his mind. **P** and **R** may be simple one-dimensional quantities, such as speed, but more generally, they will be multi-dimensional vectors (denoted by **BOLD** font) that define mental representations of states of the world in terms of multiple attributes r_k and p_k of those states:

$$\mathbf{R} = \begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_Z \end{pmatrix}; \quad \mathbf{P} = \begin{pmatrix} p_1 \\ p_2 \\ \vdots \\ p_Z \end{pmatrix} \quad \dots(4-7)$$

Where Z is the total number of attributes that define the state. The individual attributes p_k might reflect the simple presence or absence of some element (car, junction, situation) in the state of the world, or a position on some continuous mental interval scale, e.g. of speed, or loudness (Gescheider, 1997). Following Carver and Scheier (1998) and Powers (2005), I use the term “reference value” for **R** when referring to a specific definition of an intended state of the world in terms of such mental constructs. More abstract goal states may be represented in more complex ways, for instance by mental equivalents of fuzzy sets (Zadeh, 1965).

A mental comparator measures the comparison signal $\mathbf{E} = \mathbf{R} - \mathbf{P}$ and generates an output $\mathbf{B} = \mathbf{f}(\mathbf{E})$ that affects the resulting behaviour. The function contains a mental model, what I shall refer to as an *internal working model*, of the way the output (ultimately a behaviour) affects the state of the external world (and hence affects **E**). The goal or reference level in RHT is the target level of risk, so RHT predicts that drivers will reduce speed when the risk they perceive is higher than their target level of risk (for instance, in fog) but will adapt to additional safety features by increasing speed. This so-called risk compensation has been observed empirically: for example, in a frequently cited study Aschenbrenner, Biehl, and Wurm (1987) found that taxi drivers in vehicles

equipped with anti-lock braking systems (ABS) drove faster, spent more time out of lane and were involved in more conflicts with other road users than a control group of drivers in similar cars without ABS. Wilde postulated that the target risk level varies idiosyncratically between individuals, being the balance between the costs and benefits of risky versus cautious driving perceived by each individual. However RHT has been criticised for proposing that the target risk level is represented mentally as an aggregated accident loss in the driving population – a kind of estimate of the statistical probability of having an accident. Critics including Fuller (2011) and Vaa (2007) have argued that drivers can have only a vague, qualitative impression of the aggregate accident rate in the driving population of which they are members, and are unable to articulate it quantitatively. Modern research in behavioural economics also suggests that human risk estimates are subject to heuristics (mental processing short-cuts) and biases that make them inaccurate (Gilovich, Griffin, & Kahneman, 2002; Kahneman & Tversky, 2000).

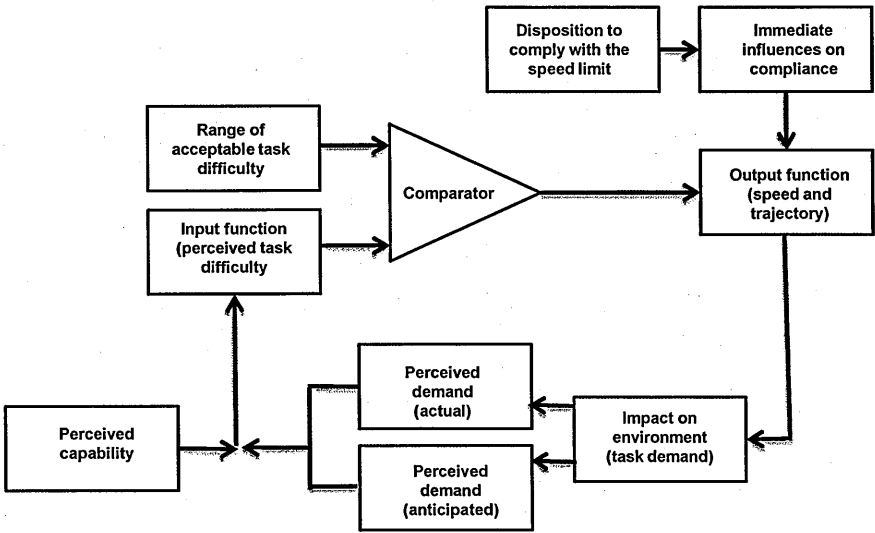


Figure 4-3. Fuller’s Risk Allostasis Theory (RAT)

Fuller (2000) proposed the Task-Capability Interface (TCI) model, also featuring a negative-feedback control loop, controlling not to maintain Wilde’s target risk level, but rather to maintain a constant perceived “task difficulty”, arrived at by combining information about the current demands of the driving task, and the current capability of the driver. After Fuller, McHugh, &

Pender (2008) found that reported task difficulty correlated closely with reported “feelings of risk”, this model evolved into Risk Allostasis Theory (RAT) (Fuller, 2011), shown in Figure 4-3.

Allostasis is used to indicate that the reference state **R** in the feedback loop – the target feeling of risk – is, in RAT, a range, rather than a single value. Fuller’s feelings of risk are conceptualised differently to Wilde’s target risk level: there is no cognitive representation of aggregate accident loss, but rather an affective response to the driving situation, associated with its perceived task difficulty. Fuller draws on Damasio’s (2003) concept of “somatic markers” – emotional responses that occur when mental representations of elements of experience (such as objects, persons and scenarios) are activated in the mind, and serve to “mark options and outcomes” (Damasio, 2003, p.148). According to Fuller (2011, p. 23) “emotional responses in the form of somatic markers arise not only from stimuli external to the driver but also from perceived discrepancies between goal states and current states”.

RAT applied to the control of speed also includes a further mechanism in addition to the feelings of risk/task difficulty feedback loop: dispositions to comply with the speed limit, and immediate influences on compliance (such as speed limit signs or enforcement measures), combine with the output of the feedback loop to determine the speed the driver adopts. The mechanism for combination is not specified in RAT; and although compliance with the speed limit might itself be considered as feedback control, it is not represented as a second feedback loop in RAT, but rather as an unspecified process of influence. Fuller (2011) does however emphasise that in RAT, risk allostasis is seen as prioritised, and influences on compliance are “secondary”.

RAT conceptualises driving essentially as a single control-loop process that maintains feelings of risk within a target range. Other researchers have challenged this perspective by pointing out that driving is a “self-paced” task – drivers can select their own speed, so usually are able to minimise risk by selecting a lower speed. Why then do drivers not simply drive slowly? How do we account for dynamic, risky driving? In RAT other motivational influences are seen as influencing where in the target range of feelings of risk the control loop will operate: so when a driver is motivated to reach a destination quickly, a higher level of feeling of risk will be accepted, and the control loop

output will be a higher speed. However we are still left with a tautology: a driver with a risk-taking style is simply a driver who is motivated to accept a higher level of risk.

Vaa's (2007) *Monitor Model* is based on an axiom that "Man's deepest and most fundamental motive is survival"; that humans must therefore possess a specialised ability to detect and avoid threats to survival; and that this "monitor" is the body. The body monitors threats not just via the senses, but via the emotions and feelings that are generated mentally in response to sensory inputs; and initiates behaviours to restore an overall "target feeling". This sounds rather like RAT; but Vaa distinguishes two "routes or modes of information processing and decision making", one predominantly conscious (based on feeling – which, following Damasio, is defined as consciously experienced affect) and one predominantly unconscious (based on emotion, defined as unconscious affect). The driver operates in the latter mode unless the driving situation is complex or unfamiliar, in which case the former mode is engaged; but the circumstances and mechanisms for this switching are not specified. Vaa proposes two "bridges" that connect the operation of these modes, but again these are not specified. In principle, personality traits and motives other than survival influence the monitoring operation, either via somatic marking or directly; but again, little is specified; and the emphasis on survival as the "most fundamental motive" suggests that the model prioritises monitoring of risk-based affect.

Whilst these models draw on principles of feedback control, they all suggest that driving behaviour is essentially determined by control of a single variable relating to perceived risk or risk-based affect. Might drivers have other goals besides managing risk? Might some of these compete with, or conflict with, managing risk?

Driving behaviour as the simultaneous pursuit of multiple goals

Näätänen and Summala (1974; 1976) proposed an alternative conceptualisation which included both a mental *motivation module*, which responds to journey goals and so-called extra motives by increasing speeds, unless otherwise restricted, and a subjective risk monitor, that, if threshold subjective risk is exceeded, intervenes to reduce speed. Speed, in this model, results from the combination of conflicting motivations. Summala (2007) extended this thinking into a *Multiple*

Comfort Zone Model in which drivers seek to keep several functional control variables within “comfort zones”. The variables he proposed are:

- Safety margin (defined in terms of space and time)
- Good or expected progress of trip
- Rule following (avoiding violations; and also conforming to social norms)
- Vehicle/road system (maintaining smooth car/road operation and performance, and acceptable levels of lateral force in turns, etc.)
- Pleasure of driving (arising from a sense of control, but also from sensation seeking, speed, acceleration and close margins)

These latter models are examples of a broader class of models of human behaviour known as goal competition or inter-goal dynamics theories (Carver & Scheier, 1998; Kruglanski, Shah, Fishbach, Friedman, Chun, & Sleeth-Keppler, 2002). Such models propose that a particular behaviour is the resultant of the combined influences of multiple goals, some complementary, some competing and some conflicting with each other. Applying this general approach to the specific case of driving suggests that behaviours such as the selection of a driving speed, or the degree of accelerator pedal depression selected in a given situation, are the instantaneous resultants of the combined influences of multiple goals.

However, for my purposes, the Multiple Comfort Zone model is incomplete. Firstly, it does not specify the mechanisms by which drivers keep the functional control variables within comfort zones, and particularly, what role perception plays in these mechanisms. Secondly, the list of control variables does not seem to reflect the diversity of goals that drivers might have on their journeys, and particularly, does not include symbolic goals, which play a major role in human behaviour (Carver & Scheier, 1998; see Chapter Eight for a discussion of symbolic goals, and Chapter Nine for an experimental study of the symbolism of driving styles). I now set out to develop a more complete inter-goal dynamics theory of driving that takes into account the diversity of goals that drivers describe themselves as pursuing when driving, their inter-goal dynamics, the

mechanisms of multiple feedback control, and the role of perception in these processes. In this new model driving behaviours, such as the selection of a driving speed, or the degree of accelerator pedal depression selected in a given situation, are the instantaneous resultants of the combined influences of multiple goals, and perceptions of the effects of immediately preceding behaviours. The model therefore includes specific mechanisms for multiple simultaneous feedback control, and the role of perception in these processes.

I begin by considering the diversity of goals that drivers describe themselves as pursuing when driving. In separate research, outside the scope of this thesis (Skippon, Vannozzi, & Flack, 2013), my co-authors and I reported an analysis of qualitative data from individual interviews, dyadic interviews and group discussions carried out to map the travel-related goals of people from two life-stage segments (young people (aged 21-25); and adult members of families with children at home), living in the UK and Malaysia. This work identified many distinct goals that participants reported pursuing when driving, and suggested they could be grouped in four broad categories:: Journey goals (those functional/instrumental goals that the driver seeks to achieve by making the journey or during it); Safety goals (functional/instrumental goals which concern the avoidance of harm while driving); Symbolic goals (which concern using driving style to signal something about oneself to other people or to oneself) and Affective goals (which concern the achievement of pleasure from driving). These are shown in Table 4-1.

There is clearly scope for complementarity, competition and conflict between goals in these different categories. Some of them, such as the safety goals, are best pursued through careful driving, low speeds, limited acceleration and early, smooth braking. On the hand, goals to complete a journey as fast as possible, symbolic goals to signal masculinity, low agreeableness or dynamic driving skill, are best pursued through dynamic driving, with high speeds, high accelerations and heavy, late braking. Different patterns of instantaneous activation among the goals will result in different driving behaviours, leading to differences in the extent to which drivers make use of the acceleration available from their vehicles, and therefore differences in the opportunities afforded to them to perceive differences in available acceleration.

Functional/ Symbolic	Category	Goal
Functional	Journey	Get to destination as quickly as possible
		Prevent other drivers messing me around
		Relax & be comfortable
		Minimise impact of journey on environment
		Use time to communicate with other people
		Use time to think about other things
		Keep fuel cost as low as possible
		Drive considerately in relation to other drivers
		Avoid penalties for driving violations
	Safety	Avoid harm to myself
		Avoid harm to others
		Avoid conflict with other drivers
		Avoid damage to my vehicle
Symbolic		Signal my masculinity to others through driving style
		Signal my adulthood/maturity to others
		Signal my dynamic driving skill to others
		Signal my careful driving skill to others
		Signal low agreeableness to others through driving style*
		Signal high agreeableness to others through driving style*
		Signal low conscientiousness to others through driving style*
		Signal high conscientiousness to others through driving style*
		Signal low neuroticism to others through driving style*
		Signal high neuroticism to others through driving style*
Affective		Conform with dynamic driving behaviour of my social group**
		Conform with careful driving behaviour of my social group**

*Participants expressed these in terms such as “Express myself”, “Show what kind of person I am”, etc. The authors assumed that these expressions relate to implicit goals to signal personality traits (see Chapters Eight and Nine for discussions of symbolic goals to signal personality).

**Social groups included family (especially parents), peers and work-groups. Participants might see themselves as members of several social groups, not necessarily with similar driving behaviours

Table 4-1. Goals when driving (from Skippon et al., 2013)

Inter-goal dynamics (IGD) model of driving behaviour

For simplicity I consider the case of driving on an extra-urban single-carriageway road. The driver has three to five controls available: the accelerator pedal, brake, steering wheel, and, in a vehicle with manual transmission, the clutch and gear selector. The driving task consists of controlling the vehicle’s speed and direction, and (when following another vehicle) its headway (separation from that vehicle). Direction, controlled using the steering, is a relatively constrained task: the driver must steer to follow the road, remaining within the lane boundaries. However the driver has much more flexibility over choice of speed and headway, and drivers do indeed make use of this, exhibiting, for instances, significant differences in speed en route (see Chapter Five, and Fuller, 2011). For this reason I focus on control of speed and headway.

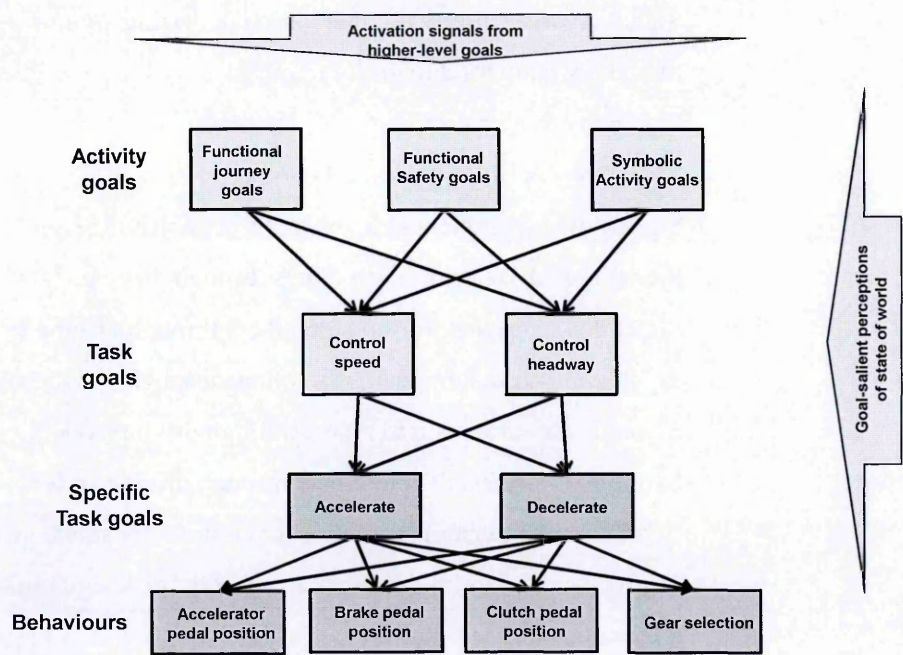


Figure 4-4. IGD-driving: Inter-Goal Dynamics (IGD) model of driving behaviour

Figure 4-4 shows the structure of the model, which I shall refer to as the IGD-driving model. Driving-specific goals are organised hierarchically into three levels. Activity-level goals represent what the driver is seeking to achieve, and are represented in three categories (Journey, Safety,

Symbolic goals¹²). Subordinate to these are two Task-level goals, Control Speed and Control Headway; and subordinate to these are two more specific Task goals, Accelerate and Decelerate.

Reference values for Task goals to control of speed and headway

Each Activity goal provides its own input to the reference value (a speed, or a headway) for each of the two Task goals, *Control Speed* and *Control Headway*. The reference value that is used by the comparator in each Task goal feedback loop is determined dynamically as a weighted sum of these inputs. If the reference values for speed and headway are R_S and R_H respectively, and there are J activity goals, then:

$$R_S = \sum_{j=1}^J \{w_{R_{Sj}} R_{Sj}\} + Err_{R_S} \quad \dots(4-8)$$

$$R_H = \sum_{j=1}^J \{w_{R_{Hj}} R_{Hj}\} + Err_{R_H} \quad \dots(4-9)$$

Where R_{Sj} is the reference value signal to the *Control Speed* task goal from the j^{th} Activity goal, $w_{R_{Sj}}$ is its weight, and Err_{R_S} is an error term that accounts for any influences from other goals not explicitly included in the model (similarly for R_{Hj} , etc.). The weights are not constant, but are determined by the current activation levels of the Activity goals. Social psychological models account for variations in the influence of goals on behaviour by associating with each goal a level of *activation* (Kruglanski et al., 2002). In the IGD-driving model, it is therefore the activation level A_j of the j^{th} Activity goal that determines the weights in equations 4-7 and 4-8. The weight $w_{R_{Sj}}$ is a function of A_j ; or, formally, $w_{R_{Sj}} = f(A_j)$. Thus the contribution each Activity goal makes to the determination of speed and/or headway depends on its current level of activation, and R_S and R_H vary dynamically, in response to context-dependent changes in the activation of the Activity-level goals.

¹² “Affective” goals are here regarded as post-rationalisations of the non-conscious pursuit of symbolic or functional goals, and therefore not included in the model. See Chapter Eight for a further discussion of the rationale for this point.

It follows that to understand how the reference values of the Task goals vary we need to model how the activation levels of the Activity goals vary. Control theory suggests one contribution to the activation level of any goal: the degree of discrepancy between the perceived state of the world and the intended goal state or reference value. A goal is highly activated, and therefore highly influential on behaviour, if there is a large discrepancy in its feedback loop, so it is far from fulfilment; and its activation level is low if there is no discrepancy, and the goal is currently fulfilled. Thus goal activation is strongly linked to perception of the current state of the world, and more particularly, to the perception of goal-salient stimuli. For example, viewing a picture of a library has been found to reduce the volume of a person's voice (Aarts & Dijksterhuis, 2003): perception of the library context causing a discrepancy in the feedback loop for the context-salient goal to be quiet. In the context of driving, hazard perception is of course highly salient to the Safety goals in Table 4-1.

The second contribution comes from excitatory and inhibitory signals from other goals – the signals that mediate inter-goal dynamics. Because people have limited resources, tangible (e.g. money, time) and mental (e.g. attention, effort), when someone is pursuing multiple goals, they must *compete* with each other to influence behaviour (Cavallo & Fitzsimons, 2012; Kruglanski et al., 2002). Some goals may directly *conflict* with one another, so that pursuit of one hinders progress towards another. Goals may also *complement* each other, when the same behaviour contributes to the successful pursuit of several goals. Goals transmit excitatory signals to subordinate and complementary goals, and inhibitory signals to all others.

Equation 4-10 expresses this formally:

$$A_j = \left\{ \sum_{n=1}^N u_{nj} X_{nj} + Err_{A_j} \right\} f(E_j) K_j e^{-\frac{t}{\tau_j}} \quad \dots 4-10$$

A_j is the net activation of the j^{th} goal. The first term on the right hand side is the weighted summation of excitation or inhibition signals from other goals: X_{nj} is the signal from the n^{th} other goal, of N goals that contribute signals to the j^{th} goal. The strengths of these signals reflect the net

activations of the goals that output them; thus X_{nj} is a function of A_n , etc. The strength of association between the n^{th} and j^{th} goals is reflected in a weight term, u_{nj} (strongly associated goals get more weight in the summation) and the valence of the association (whether excitatory or inhibitory) is reflected in the sign of u_{nj} . An error term Err_{A_j} is included to account for any contributions from unknown goals.

The term $f(E_j)$, is the comparison signal in the feedback loop of the j^{th} goal. $f(E_j) = 0$ when E_j is zero, but the larger the discrepancy then the larger is this term. This term provides the mechanism whereby goals are activated by perception of stimuli in the environment. Suppose the j^{th} goal is receiving some net level of input excitation from other goals, but currently $P_j = R_j$, so E_j is zero and the goal is not activated. The presence of a new stimulus may cause a change in P_j , so that a discrepancy E_j opens up; the j^{th} goal then becomes activated.

The third term $K_i e^{-\frac{t}{\tau_j}}$ reflects the decay in net activation over time in the absence of excitatory inputs. Without such a term, goals would remain activated after any instance of excitation, no matter how long ago that instance had occurred, and over time more and more goals would be active simultaneously. The decay time-constant, τ_j , determines how quickly this decay occurs. It depends on the overall level of energy the person has (being shorter when the person is tired); and on the recent activation history of the j^{th} goal (being longer if the j^{th} goal recently been active).

In the IGD model of driving, the Activity goals receive excitatory and inhibitory inputs from higher level goals, including chronically active goals that are reflected in personality traits. Thus the pattern of activation of the Activity goals is determined both by goal-salient perception of the driving situation, and by the activation states of higher-level goals, as reflected in personality. The model thus incorporates the role of situationally-specific perception, and individual differences, in determining driving behaviour.

Reference values for subordinate, specific Task goals, determined by outputs from superordinate

Task goals

Equations 4-8, 4-9 and 4-10 determine the reference values for the Task goals, *Control Speed* and *Control Headway*. Similar equations define the reference values R_A and R_D for the two subordinate specific Task goals, *Accelerate* and *Decelerate*, that implement the control of speed and headway:

$$R_A = w_{R_{AS}} R_{AS} + w_{R_{AH}} R_{AH} \quad \dots(4-11)$$

$$R_D = w_{R_{DS}} R_{DS} + w_{R_{DH}} R_{DH} \quad \dots(4-12)$$

Where R_{AS} and R_{AH} are the reference values output by the *Control speed* and *Control headway* Task goals to the *Accelerate* goal respectively; $w_{R_{AS}}$ and $w_{R_{AH}}$ are their weights; and likewise for the *Decelerate* goal. These specific task goals in turn direct specific behaviours involving the appropriate combination of accelerator pedal, brake, and clutch positions, and gear selection.

Equations (4-8) to (4-12) reflect explicit mechanisms by which the dynamics of goal complementarity and conflict affect driving speed and headway. Consider speed: it seems reasonable to assume that the reference values contributed by the safety goals are low, as are those contributed by goals such as *Keep fuel cost as low as possible*, *Minimise impact of journey on environment*, *Relax & be comfortable*, *Drive considerately in relation to other drivers*, *Signal my careful driving skill to others*, and *Signal high agreeableness to others through driving style*. The goal to *avoid speeding penalties* may also contribute a low reference value for speed control when driving on a road where there is a speed limit. On the other hand, the goals to *Get to destination as quickly as possible*, *Prevent other drivers messing me around*, and the symbolic goals to *signal my masculinity to others through driving style*, *signal my dynamic driving skill to others*, *Signal low agreeableness to others through driving style*, *Signal low conscientiousness through driving style*, *Signal high neuroticism to others through driving style*, and *Conform with the dynamic driving styles of my social group*, are likely to contribute higher reference values. The reference value in the speed control loop will depend on the relative contributions of each, which in turn will depend on their relative weights (characteristics of the individual) and relative activations (determined in part by higher level goals, and in part by perceived situational factors).

The IGD-driving model involves a hierarchical organization of goals. Carver and Scheier, 1998, and Powers, 2005, developed the concept of hierarchical organization in considerable depth. Carver and Scheier's hierarchy includes four qualitatively different levels of goals, from high-level, abstract system-concepts (such as the ideal self a person aspires to be), through principles (such as to be considerate) and activity programs (such as to drive a friend to the shops) to specific behavioural sequences (such as to depress the accelerator pedal). Activity and Task goals in the IGD-driving model are broadly similar in level of abstraction/specificity to the lower two tiers in Carver and Scheier's theory. While activation of lower-level goals is situationally specific, higher-level goals tend to be chronically active, and are pursued in many situations. A person's higher level goals therefore tend to be predictive of their behaviour generally, across situations and across time, so they are related to the personality traits that are attributed to a person (Carver & Scheier, 1998). Since high-level goals determine the reference levels and activation states of lower-level goals, this suggests that driving behaviour will be influenced by them, and that this will be reflected in associations between driving behaviour and personality traits.

There is a degree of consensus in modern personality and social psychology that the five factor model (FFM) captures the main independent dimensions of personality (Costa & McCrae, 1995; Goldberg, 1981; Liebert & Liebert, 1998; McCrae & Costa, 2003). In the FFM, personality is represented by the continuous factors neuroticism, extraversion, openness to experience, conscientiousness, and agreeableness. There have been a few studies of driving behaviour using the FFM, mainly focused on accident risk. Sumer, Lajunen, and Ozkan (2005) used a five-factor measure, the Big Five Inventory (BFI) (Benet-Martinez & John, 1998) to study accident risk in a sample of Turkish drivers. They found that all five factors had indirect effects on accident risk, mediated by their effects on "aberrant driving behaviour". Low conscientiousness scores were associated with higher accident risk and more aberrant driving behaviours, as, to a lesser extent, were low agreeableness scores. Extraversion and neuroticism had weak positive correlations with aberrant driving behaviours and indirectly with accident risk. Conscientiousness was also found to correlate negatively with accident frequency by Arthur and Graziano (1995), and agreeableness

was negatively correlated with accident and driving penalty rate in a study of college students by Cellar, Nelson, and Yorke (2000). Benfield, Szlemko, and Bell (2007) found weak negative correlations between agreeableness and conscientiousness, and various measures of driver anger and aggressive tendencies. All of these studies used self-reports, typically of accident frequency, rather than direct measures of driving. Af Wahlberg (2009) has criticized this approach as suffering from “common method variance”, though this critique is itself controversial (de Winter & Dodu, 2010; af Wahlberg, Dorn, de Winter, Dodu, & Freeman, 2012). Since the accident data and the personality measures are both derived from self-reports, biases introduced by this method will be common to both data sets, reducing their independence and distorting the calculation of correlation coefficients.

Other studies, also focused on accident risk, have used other measures of personality traits. Ulleberg (2002) found that risky driving by young drivers was associated with two “sub-types” of personalities, represented by, in one case, low altruism, low anxiety and high sensation seeking, and, in the other, by high aggression, high anxiety and high sensation seeking. In a later study (Ulleberg & Rundmo, 2003) the authors found that the combination of high aggression and high sensation seeking was associated with self-reported high-risk attitudes to driving among more experienced drivers, while the combination of high anxiety and high altruism was associated with self-reported low-risk attitudes to driving. Sumer (2003) found that sensation seeking was positively correlated with driving speed. Jonah (1997) in a review of 40 studies, found sensation seeking correlated with various measures of “risky driving” with correlation coefficients in the range 0.3 to 0.4. Lajunen (1997) compared national means on the three factors of the Eysenck Personality Questionnaire (EPQ) (Eysenck & Eysenck, 1975), extraversion, neuroticism and psychoticism, with traffic fatality rates in 35 countries. Extraversion was positively correlated to the rate of fatalities, while neuroticism correlated negatively. Lajunen reviewed a number of other studies using the Eysenck model, concluding that results about the relationship between extraversion, neuroticism and accidents were rather mixed. Furnham and Saipie (1993) found that psychoticism was higher in a group of drivers with driving convictions than a group without. EPQ psychoticism is related to, though not identical with, low agreeableness in the FFM.

There is evidence, then, that personality traits relate to accident risk in driving. However accidents are distal consequences of behaviours, in the sense that most drivers, even risky ones, have them infrequently compared with their overall time spent driving. It may be that driving *style*, the pattern of driving behaviour that drivers engage in constantly while driving, is more proximally related to personality traits.

A model for perception of available vehicle acceleration in naturalistic driving

I now combine elements of the discussions above of perception of acceleration while driving, and the influence of driving style on opportunities to perceive it, to develop a model for perception of the acceleration available from a vehicle in naturalistic driving.

Consider a vehicle being driven at constant speed on a flat, straight road in a fixed gear. If the driver depresses the accelerator pedal, the engine delivers more torque and the vehicle accelerates with acceleration rate A . The rate will be determined by the torque, the mass of the vehicle, the rolling resistance and the aerodynamic drag. Now consider the same vehicle with a different powertrain (engine, electric motor, or both) that makes more power available. The driver could achieve the same acceleration rate, A , with less accelerator pedal depression, or achieve a higher acceleration rate, A^* , with the same accelerator pedal depression. Most of the range of possible acceleration rates could be experienced with both powertrains, so in sub-maximum accelerations it would be difficult to distinguish between them. However the highest acceleration rate achievable at maximum pedal depression would always be higher with the second powertrain than the first.

We can define a variable, available vehicle acceleration, VA , which represents the acceleration rate available from the vehicle at a given combination of initial speed and load, gear selection and accelerator pedal depression, PD :

$$VA = f(\text{speed}, \text{load}, \text{gear}, PD) \quad \dots(4-13)$$

The stimulus that a driver experiences, the physical acceleration A , will be a function of VA , initial speed and load, gear selection and accelerator pedal depression:

$$A = f(VA, \text{speed}, \text{load}, \text{gear}, PD) \quad \dots(4-14)$$

At full pedal depression A equals $VA_{\max}(\text{ISLG})$, the maximum acceleration available from the vehicle at a given combination of initial speed, load and gear selection.

Differences in VA will be reflected in the distribution of possible accelerations, $p(A')$, which will be zero for all values of $A > VA_{\max}(\text{ISLG})$, and will depend on the accelerator pedal depression, PD , when $A \leq VA_{\max}(\text{ISLG})$.

To simplify the discussion, I shall define the combination of initial speed, load, gear selection and accelerator pedal depression (all of which are under the driver's control) as the *control condition* CC . In naturalistic driving, there will be a distribution of control conditions, so the distribution of actual accelerations can itself be broken down into two terms:

$$p(A) = p(A|CC)p(CC) \quad \dots(4-15)$$

Here $p(A|CC)$ is the probability of obtaining physical acceleration A given control condition CC . It represents the performance characteristics of the vehicle, and depends on the relationship between A , VA and CC given by equation (4-14). $p(CC)$ is the distribution of control conditions, which can be further broken down as follows:

$$p(CC) = p(CC|ST)p(ST) \quad \dots(4-16)$$

where $p(CC|ST)$ is the probability that the driver will adopt control condition CC in driving situation ST , and so represents the driving behaviour of the driver, which is determined by multiple simultaneous goal pursuit as reflected in the IGD-driving model outlined earlier. The factor $p(ST)$ is the distribution of driving situations in the drive.

Combining equations (4-15) and (4-16), we have a model for the distribution of actual accelerations in naturalistic driving:

$$p(A) = p(A|CC)p(CC|ST)p(ST) \quad \dots(4-17)$$

When the actual acceleration is A , the driver forms a sensory estimate of acceleration SA . At any given driving moment, the sensory estimate of acceleration is given by the application of an inference rule to the posterior distribution $p(A|SA)$. In common with other researchers I assume that the inference rule is a MAP estimator, i.e. the perceptual estimate is based on the most likely acceleration in the posterior distribution. The posterior distribution is therefore:

$$p(A|SA) \propto p(SA|A)p(A') \quad \dots(4-18)$$

Where $p(SA|A)$ is the likelihood function for A , and $p(A')$ is the Bayesian prior assumed distribution of possible accelerations. The prior distribution $p(A')$ is not necessarily the same as the distribution of actual accelerations in the drive, $p(A)$. This raises an interesting question. The priors in Bayesian models, such as the low-velocity prior in Ascher and Grzywacz's (2000) speed perception model or the zero linear acceleration prior in the acceleration and tilt model of MacNeilage et al. (2007), are treated as invariant properties of the perceptual system, with the implication that are hard-wired; the developmental aspects of priors are not generally discussed. While the invariance assumption could suggest a genetic origin (priors reflect evolved adaptations), an alternative is that priors have a developmental origin, i.e. they are learnt through experience with the visual world. There is evidence for environmental effects on development of visual processing: for instance, cats raised for the first three months of life in a visual environment consisting solely of vertical lines are subsequently unable to see horizontal lines (Blakemore & Cooper, 1970). It may be plausible that low-velocity and zero-acceleration priors are the result of learning processes in infancy.

In driving, the actual distributions of speed and acceleration are not well represented by low-velocity and zero-acceleration priors. For instance, Tong (2009), in a study of naturalistic driving using instrumented cars, found that cars were accelerating, on average, around 35% of the time. If we propose that priors might be learnt, rather than innate, these learning processes might extend through the life-course rather than being restricted to infancy. We might then form a hypothesis that drivers learn, and apply, a contextualized, driving-specific prior distribution based on their own driving experience. As experience develops, the driver's driving-context-specific prior $p(A')$ may tend towards the $p(A)$ she/he has previously experienced. This in turn would depend on the

driver's own driving style, the range of driving situations he/she commonly experiences, and the available performance of his/her vehicle, and would provide a mechanism whereby prior experience of driving and vehicle performance might affect perception of acceleration and speed. This hypothesis leads to testable predictions: for instance, the effect of reduced contrast on speed perception should be lower for experienced drivers compared with novices; and experienced drivers with smooth driving styles should perceive the same visual acceleration as lower than drivers with high-acceleration driving styles, especially when sensory inputs are attenuated (e.g. in low contrast visual environments).

Where the sensory information consists of multiple cues, each gives rise to a sensory signal. Assuming that the sensory signals present are estimates of acceleration based on visual cues (A_V), vestibular cues (A_O), auditory loudness cues (A_L), and auditory frequency cues (A_F), and that these are independent, the posterior distribution becomes:

$$p(A|A_V, A_O, A_L, A_F) \propto p(A_V|A) p(A_O|A) p(A_L|A) p(A_F|A) p(A') \quad \dots(4-19)$$

So the posterior distribution is proportional to the product of the individual likelihood functions for each cue, and the assumed prior distribution. These in turn depend on the reliability, or signal-to-noise ratio, for the cue or prior concerned.

Assuming that the likelihoods are conditionally independent and normally distributed, the MAP estimate of acceleration is a weighted average:

$$\hat{A} = W_V A_V + W_O A_O + W_L A_L + W_F A_F + W_P A_P \quad \dots(4-20)$$

where \hat{A} is the cue-combined weighted estimate of A , A_P is the prior estimate, and the weights for each cue are given by equation (4-3).

The model is summarized in Figure 4-5. Clearly in naturalistic driving many factors influence the perception of vehicle acceleration, and perceiving real differences between, say, one powertrain and another, or one fuel and another, may be difficult. Indeed, given the influence of prior assumptions of acceleration, a hypothesis could be developed that in some circumstances perceived

differences actually relate to different priors resulting from knowledge that the vehicle or fuel is different, rather than different sensory experiences.

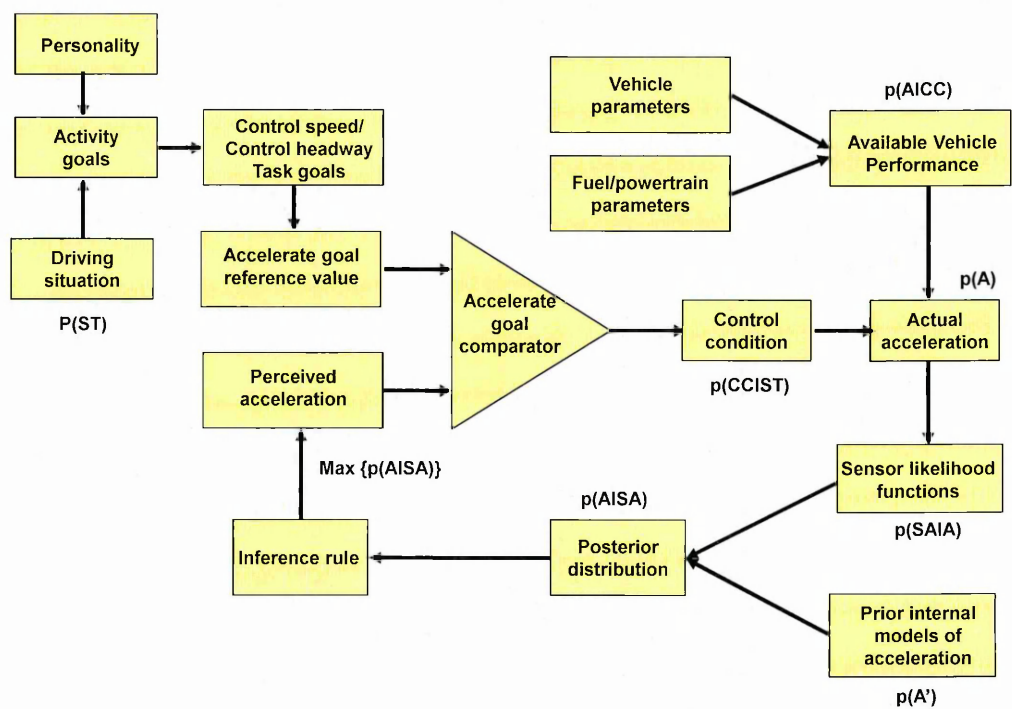


Figure 4-5. Model for the perception of vehicle acceleration in naturalistic driving

The model locates perception of acceleration within the feedback loop of the subordinate Task goal that determines acceleration, one of two that implement the superordinate Task goals to control speed and headway. Reference values for Speed and Headway are determined by weighted sums of inputs from higher-level Activity goals, with the weights being determined by the activation levels of the Activity goals, which in turn depend on the immediate driving situation, and excitatory/inhibitory signals from still higher-level goals (reflected in personality traits). They determine the driver's choice of gear and accelerator pedal depression (the control condition). The feedback loop determines whether the perceived acceleration delivered by the control condition selected matches the required (reference value) of acceleration; if there is a discrepancy, then the control condition is altered to reduce the discrepancy.

A special case can be considered in which the model is simplified. This is the case where, rather than naturalistic driving, the driver carries out a specified control action: fully depressing the accelerator pedal, starting from a defined initial speed, load and gear. In this case the effects of

driving behaviour are controlled for, and the acceleration is $VA_{\max}(\text{ISLG})$, the maximum available vehicle acceleration (in that initial speed, load and gear condition). Thus $p(A) = 1$ for $A = VA_{\max}(\text{ISLG})$, and $p(A) = 0$ for $A \neq VA_{\max}(\text{ISLG})$. This represents a simple situation where perception of maximum available vehicle acceleration can be compared directly. Experiments based on this situation will be described in Chapter Six.

Chapter Five. Perception of available vehicle acceleration and responsiveness in naturalistic driving

In this chapter I set out to test several predictions of the IGD model of driving, focusing on the perception of dynamic vehicle performance in naturalistic driving, the various influences on it, and its relationship to driving behaviour. I consider two key aspects of dynamic performance, acceleration and responsiveness.

The IGD-driving model predicts that drivers will experience different accelerations during a drive if the available vehicle acceleration (a characteristic of the vehicle) is different. Through these differing experiences they should be able to perceive differences in available vehicle acceleration. Thus my first hypothesis was:

H1: Drivers can perceive differences in available vehicle acceleration in naturalistic driving.

In the IGD-driving model, speed is controlled towards a reference (target) value in a feedback loop that compares perceived speed with the reference value, and adjusts accelerator pedal depression (and brake position) to reduce any discrepancy. The reference value is a weighted sum of inputs from Activity goals, whose relative weights adjust continuously as their activation levels vary in response to changes in the perceived driving situation (equation 4-8). The reference value for speed will be higher on a straight section of road than in a bend because safety goals (which contribute lower reference values to the weighted sum) will have lower activation (and lower weight in the summation) since the risk is lower. Thus when emerging from a bend onto a straight section, the reference value for speed will increase, and the driver will respond by accelerating to reach the revised target.

Manipulating the available vehicle acceleration provides an empirical test of this feedback control. The higher the available vehicle performance, the less accelerator pedal depression will be needed for the driver to achieve the new target speed in situations such as described above. Thus over the course of a naturalistic drive that affords multiple acceleration situations, the driver's mean acceleration pedal depression should be lower, the higher the available vehicle performance. Thus my second hypothesis was:

H2: Driving behaviour in naturalistic driving will be affected by differences in available vehicle acceleration. In particular, mean accelerator pedal depression will be lower when available vehicle acceleration is higher.

In addition to changes in their activation levels as a result of perceived changes in the driving situation, the activation levels of specific Activity goals may be changed as a result of extrinsic motivational factors such as the presence of children in the car (raising the activation of safety goals), being late for an important appointment (raising the activation of the goal to complete the journey as quickly as possible) or the presence of an attractive opposite-sex passenger (raising the activation of symbolic goals (Skippon, Diels, & Reed, 2012). The IGD-driving model predicts that these changes in goal activation will lead to changes in driving behaviour. For instance, raising the activation of the goal to complete the journey as quickly as possible should lead to higher mean accelerator pedal depression. Further, these changes in behaviour may afford different opportunities to perceive available vehicle performance: making more and faster accelerations during a drive should afford more opportunity to perceive available vehicle acceleration. Thus we might expect to see an interaction between the effects of goal activation and available vehicle acceleration on perceived acceleration. My third hypothesis was therefore:

H3: (a) Driving behaviour; (b) Perception of available vehicle acceleration are affected by journey-specific goal activation.

Finally the IGD-driving model predicts that the activation levels of Activity goals will be affected by excitatory and inhibitory signals from chronically active higher-level goals/personality traits, so individual differences in personality traits should lead to differences in driving behaviour, and therefore differences in the opportunities afforded to perceive available vehicle performance. My fourth hypothesis was therefore:

H4: Individual differences in chronically active higher-level goals / personality traits will be associated with differences in (a) Driving behaviour; (b) Perception of available vehicle acceleration.

In addition, I tested a similar set of hypotheses (H5; H6; H7(a) & H7(b); H8(a) & H8(b)) with respect to the *responsiveness* of the vehicle.

Methodology: Driving simulation optimizes trade-off of internal and external validity

Perhaps the obvious tool to manipulate the vehicle performance experienced by participants would be real vehicles. The vehicle itself, and/or its fuel, could be varied, and its performance evaluated by drivers, either in naturalistic, real-world driving or in more controlled conditions on a test track. Driving simulation offers a third alternative. A driving simulator consists of a physical representation of the driving position and controls (often a complete vehicle); a model of a driving environment, through which the vehicle appears to the driver to move; a model of the vehicle dynamics, which translates control actions of the driver into movement of the vehicle through the virtual driving environment; and one or more cueing systems that create a perception of movement through the virtual environment. Driving simulation enables a high level of experimental control – driving situations can be replicated from drive to drive and participant to participant with high reliability. In addition, it is possible to simulate driving situations in complete physical safety that might elicit unsafe driving behaviour from some participants. Driving simulation also offers high measurement accuracy, and the ability to manipulate aspects of vehicle performance independently.

The three different options, field studies in a real car, test track studies in a real car, and driving simulation, each offer different trade-offs of internal and external validity. Internal validity (Campbell & Stanley, 1963) is the ability to plausibly demonstrate a causal relationship between manipulation of independent variables and measurement of dependent variables. A causal relationship may not be plausibly inferred if confounding variables, not controlled in the experiment, could also have caused the outcome. Among the potential threats to internal validity identified by Campbell and Stanley, and Cook and Campbell (1979), is *history*: factors that may change in the participant's environment, between experimental treatments, that are outside the experimenter's control. In a field study of naturalistic driving in real traffic, there are potentially many such factors: differences in the driving conditions, traffic density, routes followed, visibility,

weather conditions, etc. Many, but not all of these can be controlled in a test track experiment. However driving simulation offers the possibility to control the majority of them; in principle all but the confounding variables associated with the participants themselves. Thus, there is a progression towards higher internal validity moving from field study via test track experiment to driving simulation experiment.

External validity refers to the generalisability of the research findings (Campbell & Stanley, 1963). Internal and external validity tend to be inversely related, in the sense that the more control is imposed to increase internal validity, the less the conditions in an experiment may be representative of the real world situations to which the experimenter wishes to generalize the findings. In driving research, where the intention is to generalize the findings to real-world driving, a field study tends to have the highest external validity. The constraints associated with a test track (safety considerations, road layout, absence of traffic, inappropriate roadside visual environment, etc) may lead to poor external validity. In principle many of these constraints can be removed by using driving simulation.

However, the external validity of a driving simulation experiment may be threatened by lack of appropriate *fidelity* of the simulation. Fidelity refers to the degree to which the simulation provides physical experiences that match what the participant would experience in the situation to which the experimenter wants to generalize: typically, real-world driving in a real car. Fidelity (sometimes referred to as *physical validity* in the simulation literature (Jamson, 1999)) is a function of how accurately the various cueing systems in the simulator (visual, auditory, motion, tactile) reproduce the vehicle and environmental stimuli that are relevant to the research question. For example, speed perception is known to be dependent on optic flow in the periphery of the field of view. If speed perception is relevant to the research question, then a simulator with a narrow field of view would have low fidelity. One way to relate fidelity to external validity is to consider the *behavioural validity* of the simulator (Jamson, 1999). Behavioural validity refers to the degree to which the simulator elicits the same behaviour by the driver as would be shown in the real-world situation to which the experimenter intends to generalize the findings.

Behavioural validity itself can take two forms: *absolute* and *relative* (Kaptein, Theeuwes, & Van der Horst, 1996; Raymond & Kemeny, 2000). Absolute validity is achieved if the behaviour elicited in the simulator is quantitatively the same as would be shown in the real-world situation under all conditions relevant to the research question. Absolute validity is not easily achieved, but has been demonstrated in several research simulators for mean speed (Alm, 1995; Carsten, Groeger, Blana, & Jamson, 1997; Harms, 1996); speed control (Blaauw, 1982; Reed & Green, 1999); and route choice (van der Mede & Berkum, 1993). Relative validity represents a lower standard, in which the quantitative *ordering* of behaviours in each relevant condition is reproduced in the simulator, but the quantitative values are not necessarily accurate. Relative validity has been established in driving simulation for many behavioural measures, such as effect of speed-reducing measures (Godley et al., 2004; Lockwood, 1997; Riemersma, van der Horst, Hoekstra, Alink, & Otten, 1990); control of lateral position (Blaauw, 1984; Carsten et al., 1997; Törnros, 1998); speed choice as a function of road width (Tenkink & van der Horst, 1991); speed when driving through a tunnel (Törnros, 1998); braking to avoid a collision (Hoffman, Brown, Lee, & McGehee, 2002; Kaptein, van der Horst, & Hoekstra, 1996); and the effect of driving experience on steering control through curves (Jamson, 1999).

Whilst absolute or relative behavioural validity is important in most simulator studies, to test hypotheses H1-H6 it was necessary to be concerned with *perceptual validity* (Kemeny & Panerai, 2003; Raymond & Kemeny, 2000). This is related to fidelity, but rather than being defined in terms of physical variables (such as image resolution) it refers to the equivalence of the driver's perceptual experience in the simulator and the real-world situation to which the experimenter wishes to generalize the findings. It therefore involves not only the properties of the simulator, but also of the driver's perceptual systems. Recall the Bayesian formulation of perception outlined in Chapter Four. The posterior distribution $p(S|I)$, the probability that the state of the environment is S , given that the sensory input is I , is given by:

$$p(S|I) \propto p(I|S)p(S) \quad \dots(5-1)$$

where the term $p(I|S)$ is the likelihood function for S , the probability that an environment S will give rise to a sensory input I . This term incorporates the fidelity of the simulator (which is the

degree to which the set of sensory inputs I_{sim} in the simulator corresponds to the set I_{real} in the real world, for the same environment S). However to achieve perceptual validity, not just I_{sim} and I_{real} should correspond, but also $p(S_{sim}|I_{sim})$ and $p(S_{real}|I_{real})$. Equation (5-1) shows that this correspondence depends not just on the fidelity of the simulator, but also on the prior distribution $p(S)$, the driver's stored representation of the prior probability of different environment properties occurring in the external world.

Assuming conditional independence of sensory inputs and prior, Bayesian theory predicts that they will be combined as a weighted sum. Where sensory information is lacking, for instance in the case of a simulator with a narrow field of view, or the absence of motion cueing, or has reduced reliability, such as an image system with low resolution, then the driver's prior representation will have higher weight. Thus the effect of a fidelity decrement is to increase the weight given to prior representations, relative to sensory inputs, in the driver's perception.

Hypotheses H1-H8 relate to naturalistic driving. In principle, a field study would offer the highest external validity for research on naturalistic driving; but it would suffer from poor internal validity. It is very difficult to represent naturalistic driving conditions on a test track, so the external validity of this method would be low. Driving simulation, on the other hand, offers the best experimental control, so highest internal validity. Its external validity is also quite high, since naturalistic driving conditions can be simulated (although fidelity issues may challenge external validity somewhat). Overall, driving simulation offers the best option for naturalistic driving studies of perception of vehicle performance. It was therefore my choice for Experiment 2.

Research design

Experiment 2 used a mixed design with three within-participants independent variables and one between-participants independent variable, each with two levels. To test hypotheses H1, H2, H5 and H6, the acceleration available from the simulated vehicle and its responsiveness were varied. The other within-participants variable was included to test hypotheses H3(a), H3(b), H7(a) and H7(b), that driver behaviour and perception of available vehicle performance would be affected by journey-specific goal activation (because different patterns of goal activation would induce

differences in driving behaviour that would result in different opportunities to perceive those performance differences). It involved manipulating the activation level of the goal to complete the journey as quickly as possible.

The between-participants variable involved comparing two groups of drivers, *general drivers* and *performance-oriented drivers*. It was intended that the latter group would tend to have more active symbolic and affective goals, that would tend to lead to more dynamic driving styles, so this variable provided a test of hypotheses H4(a), H4(b), H8(a) and H8(b).

It is not possible to manipulate personality traits experimentally. However hypotheses H4(a) and H8(a) were investigated further by measuring personality traits via a self-report questionnaire, and exploring associations between them and driving behaviour¹³.

A full factorial design was not practical, since it would have required that all participants experience each combination of within-participants conditions, making $2 \times 2 \times 2 =$ eight drives in all. Allowing time for briefing, familiarization, and questionnaire completion, participation would have required around 6 hours per participant, which experience at TRL with other simulation studies suggested would lead to substantial fatigue effects, difficulty with recruitment, and high rates of failure to complete participation. Accordingly a less ambitious design was adopted, which only required participants to complete four experimental drives each. In this design participants from each driver group were randomly allocated to three blocks. In each block, two of the within-participants variables were varied, and one was fixed. This design, shown in Table 5-1, enabled within-participants comparisons to be made with 16 participants per block (in fact slightly fewer participants actually completed all the experimental drives). All main effects, two-way interactions between any pair of the three within-participants variables, and three-way interactions between any pair of them and driver group, could be assessed. In contrast to a full factorial design, however, it

¹³ Such analyses cannot test causal relationships: hence I refer to “investigation” rather than “testing” of H3(a), H3(b), H6(a) and H6(b).

was not possible to assess three-way interactions between the within-participants variables, or four-way interactions between all variables.

Experiment Block	Within-participant variables	Fixed condition	Between-participant variable
1	Goal condition (2 levels: relaxed vs. time pressured) × Vehicle acceleration (2 levels: low vs. high)	High responsiveness	2 Driver groups: performance-oriented (N=8) and general (N=8)
2	Goal condition (2 levels: relaxed vs. time pressured) × Responsiveness (2 levels: low vs. high)	High vehicle acceleration	2 Driver groups: performance-oriented (N=8) and general (N=8)
3	Vehicle acceleration (2 levels: low vs. high) × Responsiveness (2 levels: low vs. high)	Time pressured	2 Driver groups: performance-oriented (N=8) and general (N=8)

Table 5-1: Experimental design

To keep the sample size manageable it was not practical to use full randomization of the within-participants conditions. Instead counterbalancing was achieved using a Latin Squares scheme, in which each condition occurred once in each ordinal position, and once before and once after each other condition.

The dependent variables are discussed in the Method section below.

Method

The TRL DigiCar driving simulator facility

Experiment 2 was carried out in the DigiCar driving simulator at TRL. Figure 5-1 shows the general configuration of the simulator, and Figure 5-2 shows an example of the forward view (taken from the rear seat).



Figure 5-1. General view of TRL DigiCar driving simulator

The simulator vehicle was a Honda Civic. Three projection screens provided a 210° forward field of view and another provided a 60° rear field of view. The resolution of the visual scene was 1280 × 1024 pixels per channel (one channel for each of the four screens), lower than a “natural” scene in real driving, but providing sufficient visual information to generate realistic driving behaviour from participants. The visuals were refreshed at 60Hz so that the driver perceived a seemingly continuous driving experience. Engine, road and traffic sounds were generated by a stereo sound system with speakers inside and outside the vehicle. The simulator used a motion system with three degrees of freedom (pitch; roll and heave) delivered by rams attached to axles under each wheel. These imparted a limited range of motion in the three axes, providing the driver with an impression of the acceleration forces and vibrations that would be experienced when driving a real vehicle. The motion system did not simulate motion in yaw, surge and sway, so the motion experience of

when cornering was somewhat limited. Compared with simulators with more elaborate motion systems, however, it had the advantage that participants walked up to and entered the car as they would a real vehicle, encouraging expectations of a close-to-normal driving experience.



Figure 5-2. Forward view from rear seat of DigiCar simulator vehicle (taken during development of the simulated route: road markings, etc. not fully implemented)

All control interfaces had a realistic feel and the manual gearbox could be used in the normal manner, enabling participants to drive the simulated vehicle through a simulated environment, which contained the road, roadside features, and other traffic. The vehicle dynamics were based on a Renault model and the simulation was implemented using OKTAL SCANeR II. The software interpreted the driver's control inputs, related them to the current vehicle status and computed a prediction of how a real vehicle would behave in the given circumstances. The system then responded to present to the driver its optimal representation of how this behaviour would be perceived through the visual, sound, and motion sub-systems. Data was then recorded relating to all control inputs made by the driver, including steering, pedals, gear, indicators; vehicle parameters such as speed and engine speed; and parameters to assess behaviour in relation to other vehicles, such as distance and time headways. As there was no particular requirement for high temporal resolution, data was recorded at 20 Hz.

Other traffic was included in the simulation in the form of “autonomous traffic vehicles” selected from a pre-existing library of different vehicle types including cars, trucks, buses, emergency vehicles, bicycles, and pedestrians. Each autonomous vehicle obeyed specific driving rules, so as to behave in a normal manner with respect to other traffic vehicles. The autonomous vehicles also had dynamic properties of their own – they appeared to pitch realistically under acceleration and braking, and vehicle graphics included body tilt and roll under braking, acceleration and turning; speed dependent rotating wheels and fully working brake, indicator, fog, and head lights. These provided additional cues to the driver and enhanced the realism of a scene.

An in-car colour LCD display was used to provide task-related information, as described later. An adjacent interview room was used for questionnaire completion and debriefing, and a waiting room was available to participants between experimental drives.

Simulated route

The simulated route consisted of 10.2 km of generic rural single carriageway A-road, with road-side features such as trees, bushes, fences, walls and buildings. It was designed to create repeated natural opportunities for accelerations. The route included appropriate signs positioned in accordance with the UK Department for Transport Traffic Signs Manual Chapter 4 (Warning Signs) 2004. Chevron signs indicated sharp turns and were presented at each of the critical bends.

The analysed section of the route was preceded by a familiarisation section and followed by a 1 km run-out section. Table 5-2 summarises the route design.

Lead-in section

The lead-in section consisted of 2.8km of unchallenging rural road with gentle bends and slight up and down gradients. It enabled participants to become familiar with the handling characteristics of the vehicle before tackling the analysed section of the route.

Analysed section

The analysed section was a winding rural road 10.2km in length. It contained 18 bends, six of which were sharp bends (Radius 45m, turning through 100-105°) and 12 were more gentle bends (Radius 90m, turning through 70°). All were flat (no gradient) and there were equal numbers of bends to the left and to the right. The route had several 500m sections that were straight with no gradient, giving adequate sight lines to facilitate the overtaking of slower moving vehicles, if necessary. The route also contained three 700m, straight, 1:8 (12.5%; 7.125°) uphill gradients that also represented good overtaking zones if required. The bends and other features were separated by short straight sections of between 100 and 300m. These sections had minor gradients and changes in direction.

Run-out section

The run-out section was 1.0km long, giving participants time in which to bring the vehicle to a halt, following verbal instruction over an intercom that they had completed the route.

Section	Description	Length	Notes
1	Familiarisation	2.8km	Undemanding road to allow familiarisation with vehicle and environment
2	Analysed section	10.2km	6 sharp bends; 12 gentle bends; 3 steep hills; 3 long straights
3	Run out	1.0km	Short straight section where the simulated drive is brought to an end
	Total	14.0km	

Table 5-2. Summary of simulated route design

Within-participants independent variables

Vehicle performance: vehicle acceleration

Two vehicle acceleration conditions were used. In the first, *low acceleration*, the basic dynamics model was used without modification. In the second, *high acceleration*, a modified version of the dynamics model was used that gave higher acceleration across all speed ranges (Table 5-3).

Speed range (mph)	Difference in time taken to accelerate across speed range (%) between low and high acceleration conditions
16-30	18
30-50	9
50-70	8

Table 5-3. Percentage acceleration difference between conditions, in three speed ranges

These differences were chosen to be somewhat smaller than the typical differences between manufacturers’ claimed 0-60mph acceleration times for medium sized family hatchback cars with 1.6 litre or 1.8 litre engines. They were somewhat larger than those typically obtained with cars driven on premium versus standard grade market fuels (in the range 1-4%), and similar in magnitude to the differences in acceleration from diesel-engine vehicles with clean diesel injectors compared with those from vehicles with injectors heavily fouled with deposits.

Vehicle performance: Responsiveness

Responsiveness was varied by introducing a 1.5s delay between the accelerator pedal action and the vehicle response in a low responsiveness condition, compared with a high responsiveness condition with no delay. The pedal delay simulated poor responsiveness as a consequence of fuel hold-up in the inlet port of a port-injected spark-ignition engine during acceleration transients (especially when the engine is cold), or “turbo lag” in a turbocharged diesel engine, but was larger than the delays typically experienced in real vehicles. The large difference was intended to be

perceivable to a majority of participants, and would therefore enable the effects of interactions with the goal condition and driver group variables to be studied.

Driving goal condition

There were two driving goal conditions:

Time pressured: Simulated drive in which participants were placed under explicit time pressure. They were briefed to imagine that they were late for an important meeting and should complete the route as fast as they could, while driving as they normally would in such a situation. A countdown timer and remaining distance indicator were visible on a display attached to the dashboard (Figure 5-3). Participants also encountered three overtaking challenges, intended to provide additional need to accelerate, and reinforce the overall sense of time pressure.

Relaxed: Simulated drive with light oncoming traffic, and a lead vehicle that adjusted its speed to remain in view but was not approached (so no overtaking was required). Participants were briefed to drive as they normally would.

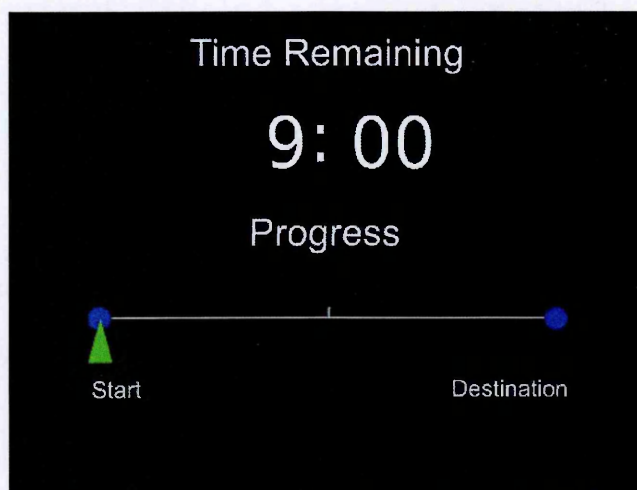


Figure 5-3. In-vehicle display screen in Time Pressured condition (showing configuration of display at start of drive)

Between-participants independent variable: Driver group

Participants were recruited into two groups:

- *General drivers*, who met the general recruitment criteria for the experiment (see Participants section).
- *Performance-oriented drivers*, who met the general recruitment criteria, and who self-reported regularly purchasing premium fuel, marketed on the basis of performance. It was assumed that, compared with the general drivers group, members of this group would tend to have more active symbolic and affective goals that would tend to lead to more dynamic driving styles.

An equal number of each group were allocated to each experimental block.

Dependent variables: perception of performance

Participants’ perceptions of acceleration and responsiveness were measured using rating scales in a post-condition questionnaire completed immediately after each experimental drive. Participants were asked to mark a position on a horizontal line, which was accompanied by verbal anchors at its centre and ends (see Table 5-4). To control for demand characteristic effects the post-condition questionnaire included a number of other questions relating to steering, brakes, etc., so that participants could not readily identify acceleration and/or responsiveness as the key experimental variables.

How did the car accelerate compared with the familiarisation drive? (mark a position on the line corresponding with your answer)		
<i>Much slower</i>	<i>Same</i>	<i>Much faster</i>
<div></div>		
How well did the car respond to the accelerator pedal compared with on the familiarisation drive? (mark a position on the line corresponding with your answer)		
<i>Much less responsive</i>	<i>Same</i>	<i>Much more responsive</i>
<div></div>		

Table 5-4. Post-condition question and response line items for perceived acceleration and perceived responsiveness

Analysis of perception data: magnitude estimation method

The perceived acceleration and perceived responsiveness data took the form of magnitude estimates by the participants on a scale from 0 to 100. The position of participants' marks on the questionnaire response lines was converted to a linear scale, with 0 representing the left hand pole of the response line, 50 the centre and 100 the right hand pole. A score of 50 thus represented a response that the perceived acceleration or perceived responsiveness was the same as during the familiarisation drive.

Descriptive statistics (means and standard deviations) were calculated for each condition within each experiment block. The data was then analysed using a separate $A \times (B \times C)$ mixed factorial ANOVA for each of experiment blocks 1, 2, and 3.

Dependent variables: induced control action and driving behaviour

Aspects of participants' control actions and the vehicle's behaviour (such as speed, rpm, accelerator pedal depression, gear selection) were logged continuously at 20 Hz. Derived measures of driving behaviour, such as time to complete to route, and route-averages of speed, engine speed, pedal positions, etc. were calculated from this data (Table 5-5).

Particular events such as the start and finish of bends, hill climbs and overtaking manoeuvres were time-stamped in the data, so that a further set of derived measures, specific to these manoeuvres, could be calculated.

Personality measurement

Personality was measured using the NEO PI-R five-factor model questionnaire (Costa & McCrae, 1992, 1995). The questionnaire has 240 items and takes participants 35-45 minutes to complete. It is scored to provide a profile with five major factors, called "domains" in NEO PI-R, each of which has six subordinate "facets". The questionnaire is not shown in full as it is subject to copyright, but Table 5-6 summarises the domains and their associated facets.

Number of gear changes	Overtake 1 - accelerator position at lane change
Time to complete (s)	Overtake 2 - accelerator position at lane change
Mean speed (mph)	Overtake 3 - accelerator position at lane change
Mean engine speed (RPM)	Overtake 1 - time in offside lane (s)
Mean accelerator pedal position	Overtake 2 - time in offside lane (s)
Mean brake position	Overtake 3 - time in offside lane (s)
Mean clutch position	Overtake 1 - average speed (mph)
SD speed	Overtake 2 - average speed (mph)
SD engine speed	Overtake 3 - average speed (mph)
SD accelerator pedal position	Overtake 1 - average accelerator position
SD brake position	Overtake 2 - average accelerator position
SD clutch position	Overtake 3 - average accelerator position
Maximum brake position	Average speed in 12 normal curves (mph)
SD lateral lane position	Average SDLP in 12 normal curves (mph)
Duration spent out of lane (s)	Average accelerator position in 12 normal curves (mph)
Duration spent out of lane (Offside) (s)	Average brake position in 12 normal curves (mph)
Duration spent out of lane (Nearside) (s)	Average speed in 6 sharp curves (mph)
Average speed on hills (mph)	Average SDLP in 6 sharp curves (mph)
Average accelerator position on hills	Average accelerator position in 6 sharp curves (mph)
Number of gear changes on hills	Average brake position in 6 sharp curves (mph)
Overtake 1 - speed at lane change (mph)	Average number of gear changes in 100m after 12 normal curves
Overtake 2 - speed at lane change (mph)	Average number of gear changes in 100m after 6 sharp curves
Overtake 3 - speed at lane change (mph)	

Table 5-5: Derived measures of driving behaviour

Factor	High scorers are...	Low scorers are...	Subordinate facets
Extraversion	Outgoing, enthusiastic	Quiet, reflective, aloof	Warmth Gregariousness Assertiveness Activity Excitement-seeking Positive emotions
Neuroticism	Prone to stress and worry	Emotionally calm	Anxiety Anger Depression Self-consciousness Impulsiveness Vulnerability
Conscientiousness	Organised, self-directed	Spontaneous, careless	Competence Order Dutifulness Achievement-Striving Self-Discipline Deliberation
Agreeableness	Trusting, empathetic	Uncooperative, hostile	Trust Straightforwardness Altruism Compliance Modesty Tender-mindedness
Openness	Creative, imaginative, accepting of change	Conventional, practical, accepting of routine	Fantasy Aesthetics Feelings Actions Ideas Values

Table 5-6. Domains and Subordinate Facets in the NEO PI-R personality inventory

Procedure

Recruitment

Participants were recruited using a screening questionnaire administered by telephone, which identified whether they met the general recruitment criteria, and, in the case of performance-oriented drivers, the performance-orientation criteria (see Participants section below).

Pre-experiment questionnaire: demographic and driving experience data

Participants completed a confidential questionnaire containing demographic information and basic information relating to their driving (annual mileage, etc.), sent to them by post for completion prior to attending the research session.

Initial briefing and familiarisation

Participants were briefed before driving the simulator using a set of standard instructions. They were told that “your driving is not being judged” and asked “not treat the simulator as a computer game”, to encourage them to focus on the task and react in a normal manner. They then completed two familiarisation drives. The first, a rural familiarisation route, took 7–10 minutes to complete and enabled the driver to become comfortable with the simulated environment and car controls. The second took place a few minutes after the first, and used the full experimental route in order to familiarise participants with the route layout. This drive was completed in the time pressured condition in order to allow participants to experience the situation prior to the experimental runs. The vehicle was configured in the low acceleration, high responsiveness condition for both familiarization drives. Participants completed the post-condition questionnaire for the first time after the second familiarisation drive. This enabled them to become familiar with the questionnaire and reduced the risk of order effects.

Experimental drives and questionnaires

Each participant completed four experimental drives, with a post-condition questionnaire after each. Questionnaires were completed in a waiting area near to the simulator.

Post-completion questionnaire and debriefing

On completion of the experimental drives and post-condition questionnaires, participants completed a simulation evaluation questionnaire to provide feedback on the simulator research from the participant’s viewpoint, and to evaluate their experience of the “realism” of the simulations. Participants were then given a written debriefing note that thanked them for their

participation, outlined the background to the research, and repeated assurances regarding confidentiality.

Personality Inventory

Participants were asked to complete the NEO PI-R inventory online at home after their session. Participants who did not have access to the internet were offered the opportunity to complete the questionnaire at TRL.

Participants

All participants were male, to control for possible gender effects. Diesel users were excluded, to control for possible effects due to greater differences between the simulated vehicle and participants' regular vehicles, given that the simulation modelled a gasoline-engine vehicle. All participants had a full UK manual driving licence, greater than five years driving experience, and drove 8,000 miles per year or greater. Potential recruits who worked in advertising, marketing, market research, car or motoring industries, petroleum industry, public relations, journalism, TV or other media were excluded (for reasons of sponsor confidentiality prior to any publication of the research).

Performance-oriented drivers

This group were recruited from the Shell UK V-Power Club member list, and were regular users of Shell V-Power, a fuel marketed as offering higher performance. Participants were selected on the basis of responses to items in the recruitment questionnaire: only candidates who valued vehicle performance above other factors such as comfort were recruited. 22 performance-oriented drivers completed the experiment.

General drivers

General drivers were recruited via TRL's database of drivers who had previously volunteered to participate in simulator research. Only those who were regular buyers of non-premium gasoline,

and had not participated in simulator research in the previous twelve months, were recruited. 21 general drivers completed the experiment.

Comparison of groups

Since performance orientation represented an existing characteristic of the participants, random allocation to the two groups was not possible, so the driver groups were matched as far as possible on potential confounding variables such as age, driving experience and annual mileage. Table 5-7 shows the mean ages and years of driving experience for the groups. Independent samples t-tests confirmed that the small differences between groups were not significant.

Group		Age (years)	Driving licence held (years)
Performance oriented	Mean	48.32	30.45
	SD	14.95	14.39
General drivers	Mean	52.71	33.38
	SD	15.51	12.54

Table 5-7. Comparison of groups: Age and years of driving experience

Group	Annual mileage (thousand miles)	Frequency	Percent
Performance oriented	5-10	6	27.3
	10-15	6	27.3
	15-20	5	22.7
	20+	5	22.7
	Total	22	100.0
General drivers	5-10	7	33.3
	10-15	8	38.1
	15-20	4	19.0
	20+	2	9.5
	Total	21	100.0

Table 5-8. Comparison of groups: Annual mileage

Inter-group differences in driving patterns, measured in terms of (a) distance travelled by participants on their two most frequent regular journeys, and (b) participants’ estimates of the percentage distribution of their driving on different road types were not significant in independent

samples t-tests. However the performance-oriented group tended to have a higher annual mileage than the general drivers group (Table 5-8).

The Theory of Planned Behaviour (Ajzen, 2005) suggests that behaviour is influenced by beliefs about how other people who are important to that person (salient referents), such as family members or partners, may view that behaviour. Since this might apply to driving behaviour in the experiment, the marital status of group members and their numbers of dependent children were compared; there were no significant inter-group differences.

Type of car	General drivers	Performance-oriented drivers
Small/Medium hatchback	10	2
Small/medium saloon	1	8
Large hatchback	4	2
Large Saloon	0	0
Estate	3	3
4 x 4 Sports Utility (SUV)	1	1
Multi Purpose (MPV)	1	0
Sports car	1	6
Mean (SD) engine size (c.c.)	1761 (529)	2615 (837)

Table 5-9. Comparison of groups: most frequently driven cars, and mean engine sizes

In Table 5-9 the two groups are compared in terms of the class of car they most frequently drove. Among general drivers the most common class of car was small/medium hatchbacks, which made up 47.6% of the total; large hatchbacks and estates made up the majority of the balance. A different picture emerged from the performance-oriented drivers group: 27.3% drove sports cars, 36.3% drove small/medium saloons. The mean engine size of vehicles driven most often by the performance-oriented drivers was 2.615 ± 0.837^{14} litres, compared with 1.761 ± 0.529 litres for the general drivers; Performance-oriented drivers tended on average to drive cars with engines nearly 50% bigger than the general drivers group.

¹⁴ For conciseness I shall use the scientific notation “mean \pm standard deviation” when reporting means with their standard deviations.

Results

Driving behaviour: selection of variables for further analysis

As shown in Table 5-5, a rather long list of driving behaviour variables was derived from the simulator data. Given the likelihood that many of these would be correlated, an exploratory factor analysis was carried out to help identify a sub-set for further analysis whose members were essentially independent of each other. The analysis was carried on the data from 14 of the first 15 variables in Table 5-5 for all experimental drives (excluding time to complete, which related directly to mean speed). Principal components extraction was used, with varimax rotation to identify orthogonal factors with eigenvalues $> 1^{15}$.

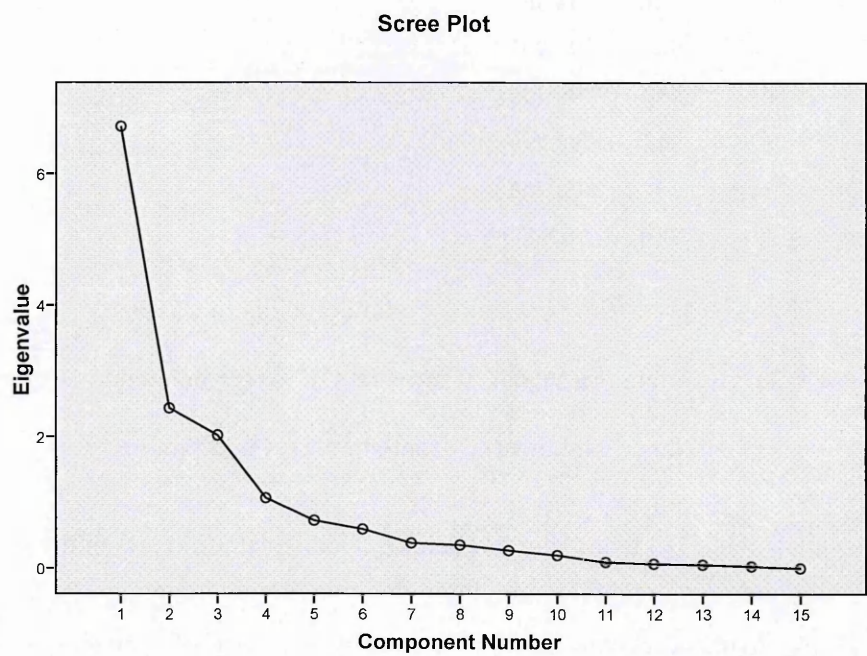


Figure 5-4. Exploratory factor analysis of measures of driver behaviour: scree plot

¹⁵ This criterion led to a four-factor solution. Inspection of the scree plot suggested that a two-factor solution might also be considered; this was explored but the two factors were subjectively less meaningful, coherent and distinctive than those in the four-factor solution.

Figure 5-4 shows the scree plot, Table 5-10 the eigenvalues and variance explained by the extracted and rotated factors, and Tables 5-11 and 5-12 the extracted and rotated component matrices with factor loadings for each variable.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.72	44.82	44.82	6.72	44.82	44.82	5.72	38.14	38.14
2	2.43	16.22	61.03	2.43	16.22	61.03	2.48	16.56	54.71
3	2.02	13.47	74.51	2.02	13.47	74.51	2.26	15.06	69.77
4	1.06	7.10	81.60	1.06	7.10	81.60	1.77	11.83	81.60
5	.72	4.83	86.43						
6	.59	3.95	90.38						
7	.38	2.54	92.91						
8	.35	2.34	95.26						
9	.269	1.792	97.049						
10	.198	1.318	98.368						
11	.094	.624	98.992						
12	.069	.457	99.449						
13	.052	.347	99.796						
14	.031	.204	100.000						
15	<.001	<.001	100.000						

Table 5-10. Exploratory factor analysis of measures of driver behaviour: eigenvalues and variance explained, extracted and rotated factors

The rotated solution contained four factors, which together explained 81.6% of the variance:

1. A “dynamic driving” factor, loaded by a variety of variables, including: mean accelerator pedal depression; mean brake pedal depression; mean, maximum, and standard deviation of engine speed; mean, maximum, and standard deviation of road speed.
2. A “lane crossing” factor, loaded mainly by: total duration out of lane, duration out of lane (offside), and standard deviation of lane position.
3. A “gear change” factor, loaded by: number of gear changes, mean clutch position, and standard deviation of clutch position.

4. A “nearside steering accuracy” factor, loaded mainly by: duration out of lane (nearside), standard deviation of lane position, and to a lesser degree standard deviation of engine speed (rpm).

Variable	Component			
	1	2	3	4
SD speed	.951	.038	.061	-.120
SD brake position	.884	-.182	-.215	.046
Mean brake position	.876	-.181	-.236	.074
SD engine speed	.857	.093	.054	-.218
Mean accelerator position	.843	-.039	-.210	.099
SD accelerator position	.795	.084	-.247	.174
Mean engine speed (RPM)	.753	-.283	-.200	-.117
Mean speed (mph)	.715	-.412	-.344	-.164
SD lateral lane position	.575	.461	.431	-.251
Duration spent out of lane (s)	.489	.780	.186	.280
Duration spent out of lane (Offside) (s)	.457	.745	.099	.430
SD clutch position	.356	-.445	.679	.045
Mean clutch position	.215	-.371	.623	.148
Number of gear changes	.303	-.524	.599	.369
Duration spent out of lane (Nearside) (s)	.261	.336	.458	-.655

Extraction Method: Principal Component Analysis. 4 components extracted

Table 5-11. Exploratory factor analysis of measures of driver behaviour: extracted component matrix

The analysis confirmed that there was substantial redundancy among the behaviour variables. For factor 1, the behavioural measures with the highest loadings were mean and standard deviation of brake position (each 0.909). However these were closely followed by mean accelerator pedal position (0.879), so this was chosen for subsequent analyses as it related more directly to the

research hypotheses (use of accelerator and brake on the experimental route were expected to be correlated since each acceleration necessitated subsequent braking to negotiate the next bend, etc.). The behavioural measures with the highest loading on each of the other factors were used in subsequent analyses. These were: *Number of gear changes*; *Duration out of lane (nearside)* and *Duration out of lane (offside)*¹⁶.

Variable	Component			
	1	2	3	4
SD brake position	.909	.137	.129	.027
Mean brake position	.909	.147	.119	-.007
Mean speed (mph)	.879	-.228	.043	.012
Mean accelerator position	.832	.262	.070	.025
Mean engine speed	.821	-.066	.114	.094
SD speed	.813	.287	.200	.373
SD accelerator position	.769	.373	-.009	-.020
SD engine speed	.725	.244	.117	.442
Duration spent out of lane (Offside) (s)	.155	.962	-.065	.075
Duration spent out of lane (s)	.148	.933	-.052	.253
Number of gear changes	.149	.011	.908	-.121
SD clutch position	.161	-.071	.844	.209
Mean clutch position	.035	-.016	.764	.093
Duration spent out of lane (Nearside) (s)	.001	.071	.049	.901
SD lateral lane position	.237	.481	.157	.693

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 5 iterations.

Table 5-12. Exploratory factor analysis of measures of driver behaviour: rotated component matrix

¹⁶ Given that the IGD-driving model is a model of driving behaviour, and the experimental hypotheses were framed in terms of behaviours, it was more appropriate to use behavioural measures than factor scores in subsequent analyses.

Experiment block 1

In experiment block 1, vehicle acceleration and goal condition were varied with constant responsiveness (zero pedal delay). Driver group was a between-participants variable. Six dependent variables were included in the analysis: perceived acceleration (magnitude estimation), perceived responsiveness (magnitude estimation), mean accelerator pedal position, number of gear changes, time out of lane (nearside), and time out of lane (offside). Multi-variate analysis of variance (MANOVA) confirmed that there was a significant main effect of goal condition on the pattern of results across the six dependent variables ($F(6,5) = 42.453, p < 0.001$).

Dependent variable	Independent variable	Df	F	p
Accelerator pedal position	Vehicle acceleration	11	2.483	0.143
	Goal condition	11	8.039	0.016
	Driver group	11	1.071	0.323
Number of gear changes	Vehicle acceleration	11	0.773	0.398
	Goal condition	11	0.085	0.776
	Driver group	11	0.036	0.852
Time out of lane (nearside)	Vehicle acceleration	11	0.102	0.756
	Goal condition	11	3.312	0.096
	Driver group	11	0.989	0.341
Time out of lane (offside)	Vehicle acceleration	11	0.752	0.404
	Goal condition	11	79.01	<0.001
	Driver group	11	0.343	0.57
Perceived acceleration	Vehicle acceleration	11	0.205	0.66
	Goal condition	11	5.199	0.044
	Driver group	11	0.207	0.658
Perceived responsiveness	Vehicle acceleration	11	0.446	0.518
	Goal condition	11	6.591	0.026
	Driver group	11	0.05	0.827

Table 5-13. Experiment block 1: Univariate ANOVA outputs for each dependent variable (vehicle acceleration, goal condition and driver group). Responsiveness was held constant (high). Red font: significant with $p < 0.05$; blue font: significant with $p < 0.10$

Univariate analyses of variance (ANOVA) were then carried out for each dependent variable. Table 5-13 summarises the ANOVA outputs for each dependent variable in turn.

There were significant ($p < 0.05$) main effects of goal condition on accelerator pedal position, time out of lane (offside), perceived acceleration and perceived responsiveness. The main effect of goal condition on time out of lane (nearside) was significant only against the more relaxed criterion $p < 0.10$. Participants in the time pressured goal condition used the accelerator pedal more than they did in the relaxed goal condition (Figure 5-5) (this effect appeared bigger for the general drivers, though the interaction was not significant). General drivers, but not performance-oriented drivers, also spent less time out of lane on the nearside (Figure 5-6). Participants spent substantially more time out of lane on the offside in the time pressured condition, but this was an artefact of the experiment since in this condition, but not in the relaxed goal condition, they had to complete overtaking manoeuvres. Perceived responsiveness was lower in the time pressured condition (Figure 5-7), as was perceived acceleration when vehicle acceleration was high (although the opposite was true when vehicle acceleration was low) (Figure 5-8).

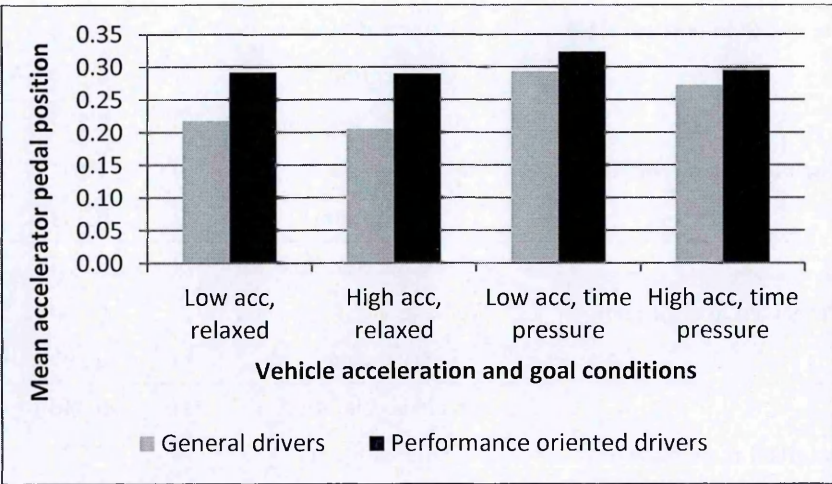


Figure 5-5. Experiment block 1: Mean accelerator pedal position vs. goal condition (relaxed/time pressured) and vehicle acceleration (low/high)

None of the main effects of vehicle acceleration and driver group on any dependent variable, nor any interactions, were significant. There were tendencies for perceived acceleration and perceived responsiveness to be higher in the high, compared with the low, vehicle acceleration condition (Figures 5-7 and 5-8). Under time pressure, there was a tendency for participants to use the

accelerator pedal somewhat less in the high, compared with the low, vehicle acceleration condition (Figure 5-5).

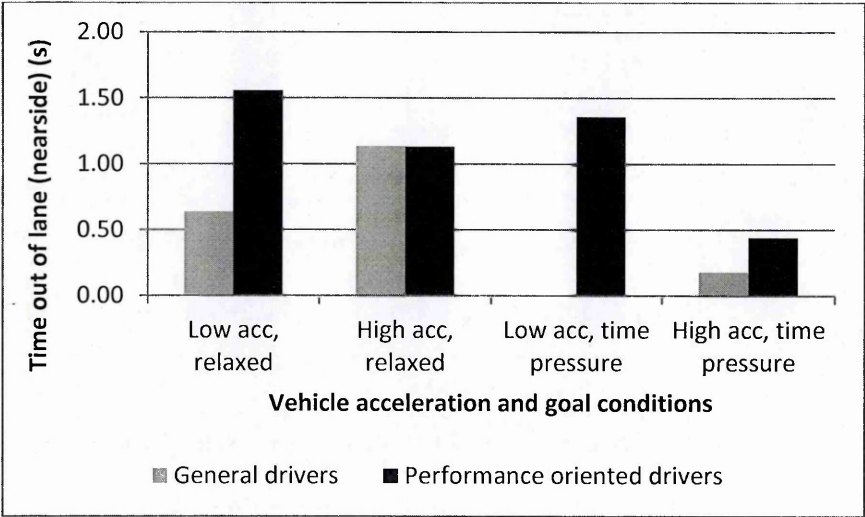


Figure 5-6. Experiment block 1: Time out of lane (nearside) vs. goal condition (relaxed/time pressured) and vehicle acceleration (low/high)

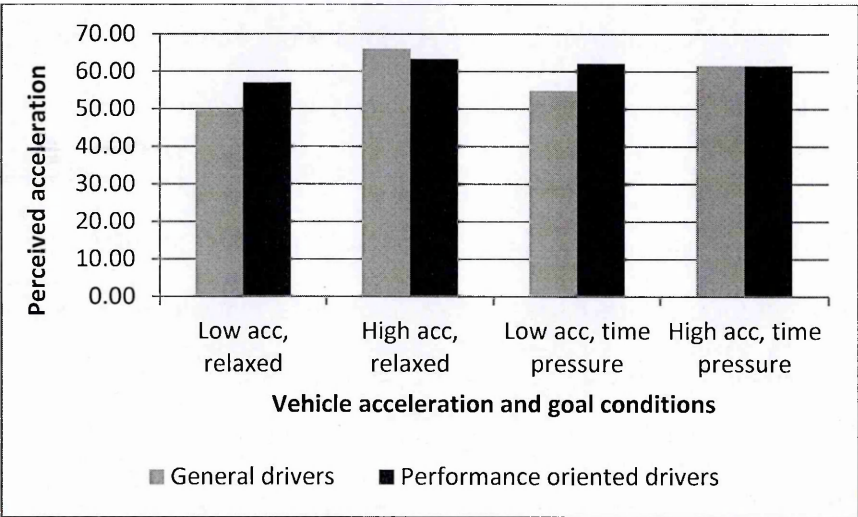


Figure 5-7. Experiment block 1: Perceived acceleration vs. goal condition (relaxed/time pressured) and vehicle acceleration (low/high)

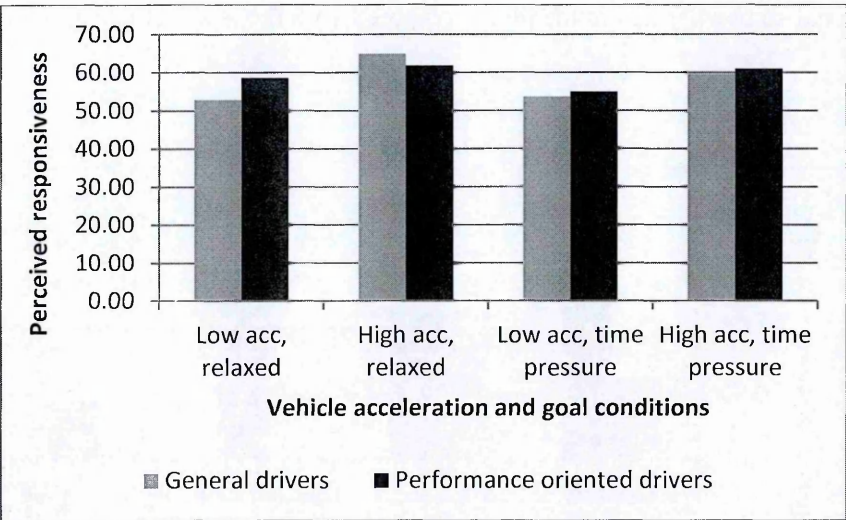


Figure 5-8. Experiment block 1: Perceived responsiveness vs. goal condition (relaxed/time pressured) and vehicle acceleration (low/high)

Experiment block 2

In Experiment block 2, responsiveness (accelerator pedal delay) and goal condition were varied with constant vehicle acceleration (high). Driver group was a between-participants variable. The same six dependent variables were included in the analysis. MANOVA confirmed that there were significant main effects of responsiveness ($F(6,5) = 19.609, p = 0.02$) and goal condition ($F(6,5) = 15.991, p = 0.04$) on the pattern of results across the six dependent variables. Univariate ANOVA was then carried out for each dependent variable. Table 5-14 summarises the ANOVA outputs for each dependent variable in turn.

Dependent variable	Independent variable	Df	F	p
Accelerator pedal position	Responsiveness	10	69.297	<0.001
	Goal condition	10	16.714	0.002
	Driver group	10	0.186	0.676
Number of gear changes	Responsiveness	10	2.215	0.168
	Goal condition	10	1.392	0.265
	Driver group	10	3.788	0.08
Time out of lane (nearside)	Responsiveness	10	5.699	0.38
	Goal condition	10	0.697	0.423
	Driver group	10	4.6	0.58
Time out of Lane (offside)	Responsiveness	10	2.744	0.129
	Goal condition	10	44.724	<0.001
	Driver group	10	1.797	0.21
Perceived acceleration	Responsiveness	10	20.2	0.001
	Goal condition	10	0.015	0.906
	Driver group	10	0.42	0.53
	Goal condition × driver group	10	7.342	0.02
	Responsiveness × goal condition	10	4.33	0.062
Perceived responsiveness	Responsiveness	10	11.026	0.007
	Goal condition	10	0.018	0.896
	Driver group	10	1.341	0.271
	Responsiveness × goal condition	10	6.357	0.028

Table 5-14. Experiment block 2: Univariate ANOVA outputs for each dependent variable (responsiveness, goal condition and driver group). Vehicle acceleration was held constant (high). Red font: significant with $p < 0.05$; blue font: significant with $p < 0.10$

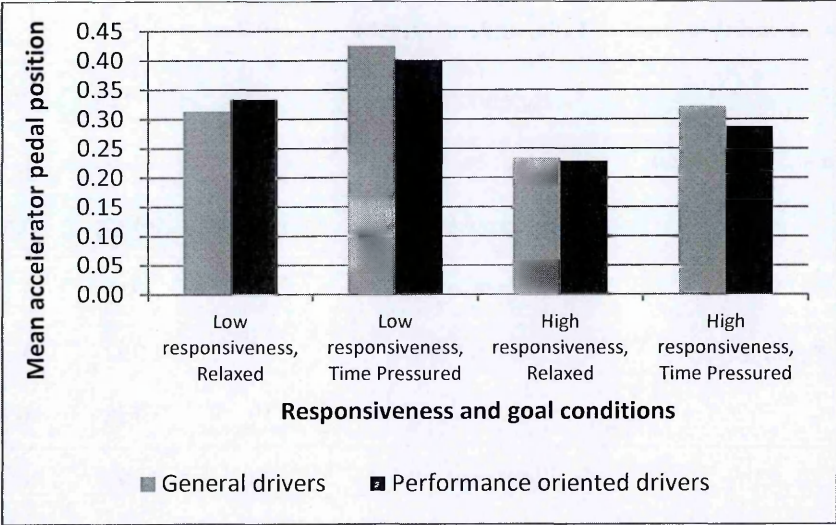


Figure 5-9. Experiment block 2: Mean accelerator pedal position vs. goal condition (relaxed/time pressured) and responsiveness (low/high)

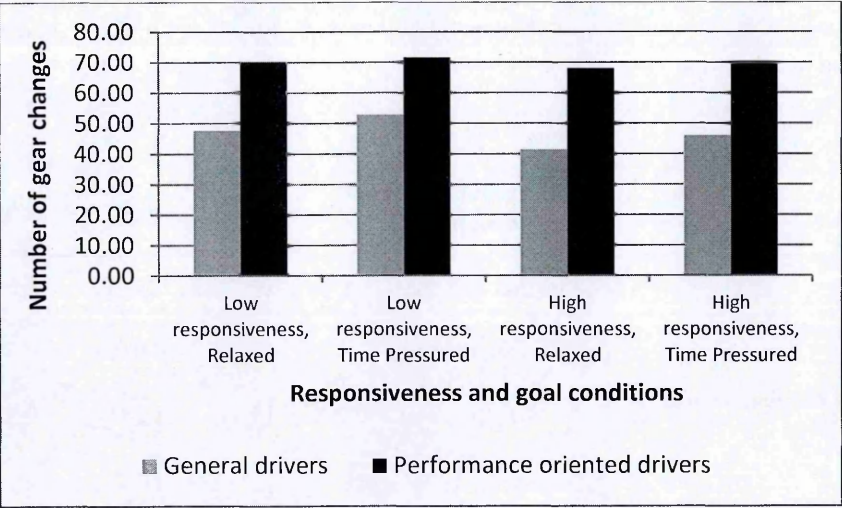


Figure 5-10. Experiment block 2: Number of gear changes vs. goal condition (relaxed/time pressured) and responsiveness (low/high)

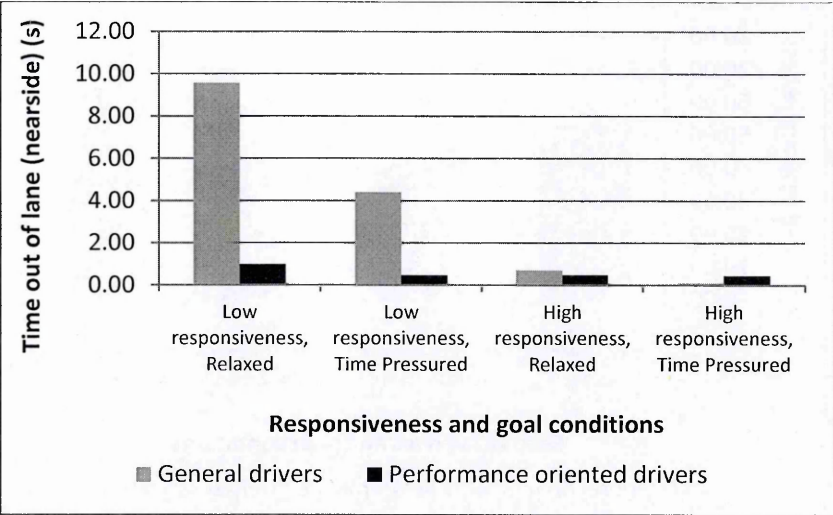


Figure 5-11. Experiment block 2: Time out of lane (nearside) vs. goal condition (relaxed/time pressured) and responsiveness (low/high)

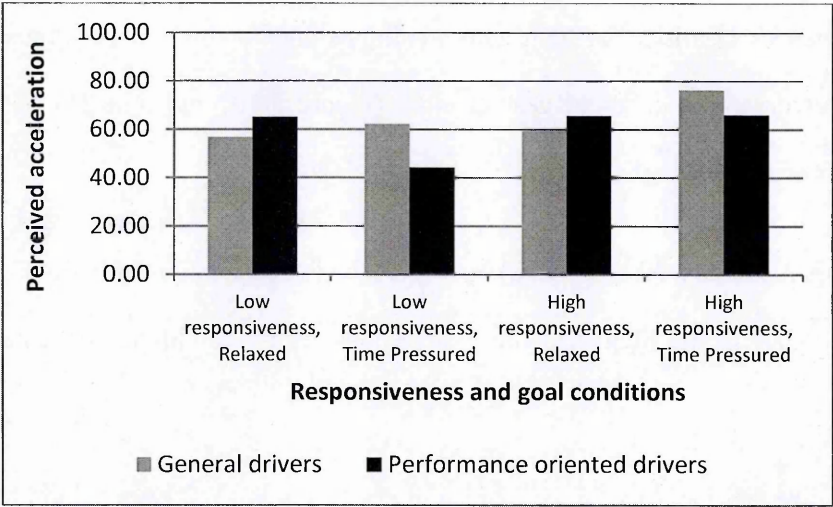


Figure 5-12. Experiment block 2: Perceived acceleration vs. goal condition (relaxed/time pressured) and responsiveness (low/high)

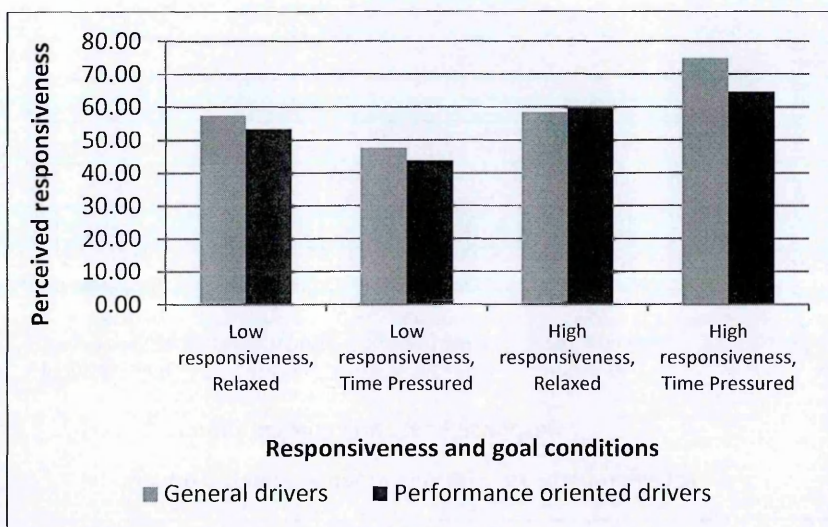


Figure 5-13. Experiment block 2: Perceived responsiveness vs. goal condition (relaxed/time pressured) and responsiveness (low/high)

There were significant ($p < 0.05$) main effects of responsiveness on accelerator pedal position, perceived responsiveness and perceived acceleration. Low responsiveness had a major impact on drivers' use of the accelerator: it was much higher in the low responsiveness condition than the high responsiveness condition, in both goal conditions and for both driver groups Figure (5-9). Among general drivers, number of gear changes (Figure 5-10) and time out of lane (nearside) (Figure 5-11) were higher in the low responsiveness condition.

Perceived responsiveness (Figure 5-12) and perceived acceleration (Figure 5-13) were both substantially higher in the high than the low responsiveness condition, particularly under time pressure.

There were significant main effects of goal condition on accelerator pedal position and time out of lane (offside)¹⁷. Under time pressure participants used the accelerator pedal more than in the relaxed goal condition (Figure 5-9). There were also significant responsiveness \times goal condition interactions for perceived responsiveness and perceived acceleration. Participants perceived responsiveness and acceleration both as lower in the low responsiveness condition, and higher in

¹⁷ An artefact of the experimental design, as the time pressured condition involved overtaking

the high responsiveness condition, than they did in the relaxed goal condition (Figures 5-12 and 5-13).

The main effects of driver group on number of gear changes (Figure 5-10) and time out of lane (nearside) (Figure 5-11) were significant, but only against the more relaxed criterion $p < 0.10$. General drivers changed gear less often than performance oriented drivers, whatever the responsiveness and goal conditions. In the low responsiveness condition they also spent more time out of lane on the nearside (in both goal conditions) than the performance-oriented drivers. The driver group \times goal condition interaction for perceived acceleration was also significant. Performance-oriented drivers tended to perceive acceleration lower compared with general drivers when under time-pressure.

Experiment block 3

In Experiment block 3, responsiveness (accelerator pedal delay) and vehicle acceleration were varied with goal condition constant (time pressured). Driver group was a between-participants variable. The same six dependent variables were included in the analysis. MANOVA confirmed that there was a significant main effect of responsiveness on the pattern of results across the six dependent variables ($F(6,6) = 11.035, p = 0.005$). Univariate ANOVA was then carried out for each dependent variable. Table 5-15 summarises the ANOVA outputs for each dependent variable in turn.

There were significant ($p < 0.05$) main effects of responsiveness on mean accelerator pedal position, number of gear changes, time out of lane (nearside), perceived responsiveness and perceived acceleration. Mean accelerator pedal position (Figure 5-14), number of gear changes (Figure 5-15) and time out of lane on the nearside (Figure 5-16) were all higher in the low responsiveness condition. On the other hand perceived responsiveness (Figure 5-17) and perceived acceleration (Figure 5-18) were both lower in the low responsiveness condition.

Dependent variable	Independent variable	Df	F	p
Accelerator pedal position	Responsiveness	11	45.551	<0.001
	Vehicle acceleration	11	10.471	0.008
	Driver group	11	0.665	0.432
	Vehicle acceleration × driver group	11	4.051	0.069
Number of gear changes	Responsiveness	11	6.056	0.032
	Vehicle acceleration	11	0.392	0.544
	Driver group	11	0.154	0.702
	Responsiveness × driver group	11	8.593	0.014
	Vehicle acceleration × driver group	11	8.952	0.012
Time out of lane (nearside)	Responsiveness	11	5.25	0.043
	Vehicle acceleration	11	1.946	0.191
	Driver group	11	2.883	0.118
Time out of lane (offside)	Pedal Delay	11	0.958	0.349
	Acceleration	11	0.008	0.929
	Driver group	11	0.524	0.484
	Vehicle acceleration × responsiveness	11	3.68	0.81
	Vehicle acceleration × responsiveness × driver group	11	3.807	0.077
Perceived acceleration	Responsiveness	11	16.226	0.001
	Vehicle acceleration	11	0.082	0.779
	Driver group	11	1.251	0.284
Perceived responsiveness	Responsiveness	11	11.758	0.004
	Vehicle acceleration	11	0.62	0.445
	Driver group	11	1.011	0.333

Table 5-15. Experiment block 3: Univariate ANOVA outputs for each dependent variable (vehicle acceleration, responsiveness and driver group). Goal condition was held constant (time pressured). Red font: significant with p < 0.05; blue font: significant with p < 0.10

There was also a significant main effect of vehicle acceleration on mean accelerator pedal position, which was lower in the high then the low acceleration condition (Figure 5-14).

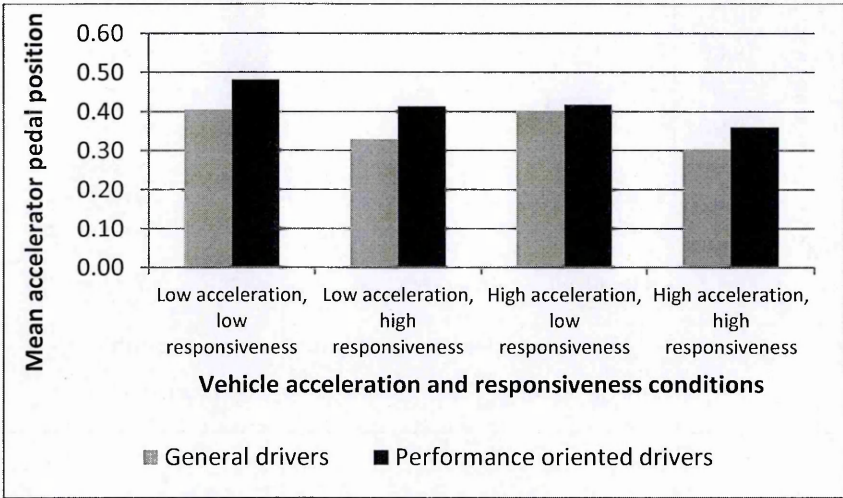


Figure 5-14. Experiment block 3: Mean accelerator pedal position vs. vehicle acceleration (low/high) and responsiveness (low/high)

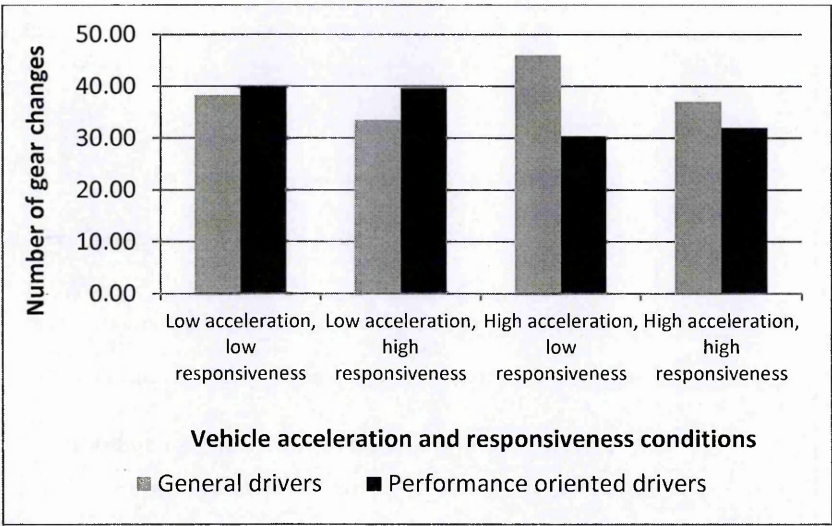


Figure 5-15. Experiment block 3: Number of gear changes vs. vehicle acceleration (low/high) and responsiveness (low/high)

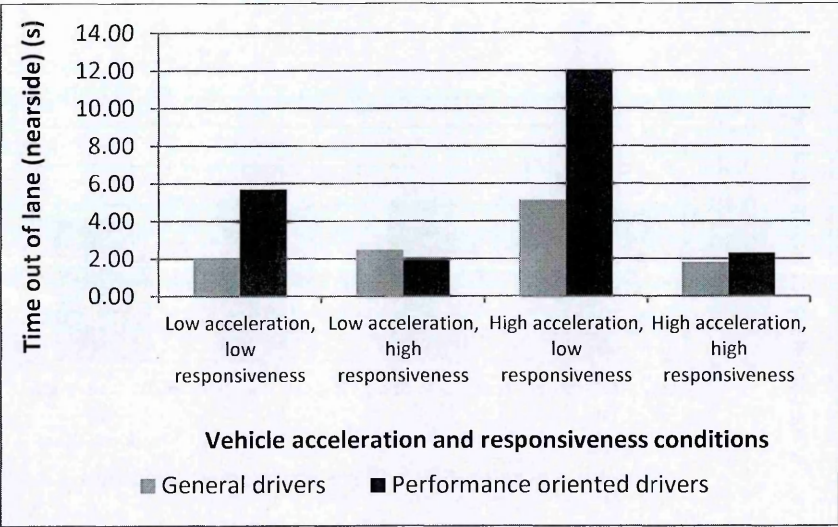


Figure 5-16. Experiment block 3: Time out of lane (nearside) vs. vehicle acceleration (low/high) and responsiveness (low/high)

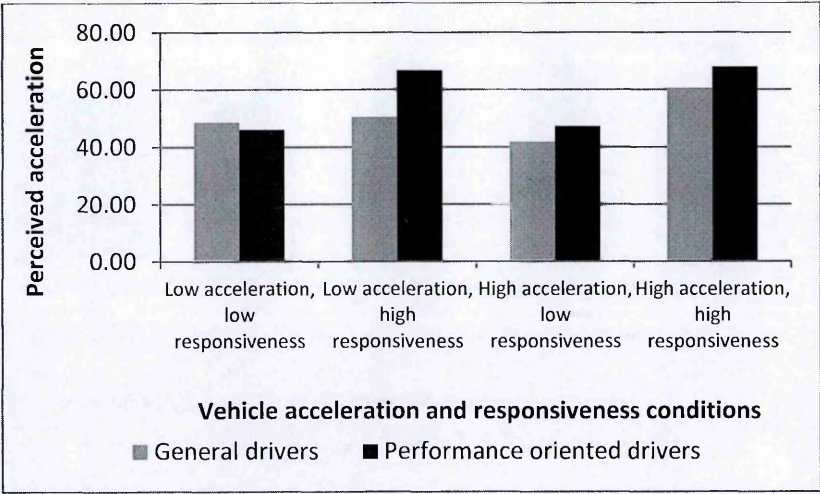


Figure 5-17. Experiment block 3: Perceived acceleration vs. vehicle acceleration (low/high) and responsiveness (low/high)

Finally there were significant perceived responsiveness \times driver group and perceived acceleration \times driver group interactions in the number of gear changes (Figure 5-15). General drivers changed gear more often in the high than the low acceleration condition, but changed gear more often in the low than the high responsiveness condition. Performance-oriented drivers changed gear *less* often in the high than the low acceleration condition, but their number of gear changes was not affected by responsiveness.

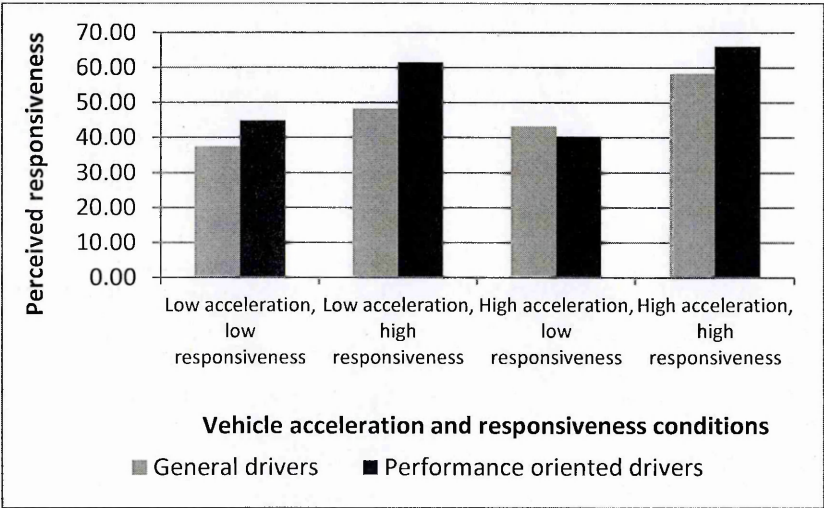


Figure 5-18. Experiment block 3: Perceived responsiveness vs. vehicle acceleration (low/high) and responsiveness (low/high)

Correlation between perceived acceleration and perceived responsiveness

Magnitude estimates of perceived acceleration and perceived responsiveness were highly correlated. The overall correlation coefficient (Pearson’s *r*) across the full set of conditions and participants was 0.796. Table 5-16 shows the correlation coefficients separately for each condition. The degree of correlation was consistently higher for high acceleration compared with low acceleration, for high responsiveness compared with low responsiveness, and for time pressure compared with the relaxed goal condition.

Goal Condition	Vehicle acceleration	Responsiveness	Correlation coefficient (Pearson's r)
Time pressured	High	High	0.894
	Low	High	0.796
	High	Low	0.731
	Low	Low	0.683
Relaxed	High	High	0.842
	Low	High	0.647
	High	Low	0.717

Table 5-16. Correlation coefficients (Pearson's r) between perceived acceleration and perceived responsiveness, for each condition

Personality and Driving Behaviour

The five-factor trait openness (Table 5-17) was associated with two measures of driving behaviour: it was positively correlated with mean clutch position, and negatively correlated with time in the offside lane during the 1st overtaking manoeuvre.

Conscientiousness was negatively correlated with two measures of driving behaviour, mean accelerator pedal position and mean speed in normal bends. This suggests that participants who scored highly on conscientiousness tended to have a somewhat slower driving style.

Extraversion was not significantly associated with any aspect of driving behaviour. However, the extraversion facet *excitement seeking* was weakly positively correlated with mean speed, suggesting that it was associated with faster driving. The facet *positive emotions* was negatively correlated with a number of aspects of driving behaviour: mean speed, engine speed, mean accelerator pedal position, mean brake position and the standard deviations of each of these. This suggests that the facet *positive emotions* was positively associated with a slower and smoother driving style involving lower overall speeds and less use of the controls.

NEO PI-R domain	Driving behaviour measure	Pearson r	p (2-tailed)
Openness	Mean clutch position	0.41	0.032
	1 st Overtake – Time in offside lane (s)	- 0.39	0.040
Conscientiousness	Mean accelerator pedal position	- 0.37	0.050
	Mean speed in 12 normal curves (mph)	- 0.38	0.045
Agreeableness	Time to complete (s)	0.52	0.005
	Mean speed (mph)	- 0.54	0.003
	Maximum speed (mph)	- 0.43	0.023
	Mean engine speed (RPM)	- 0.40	0.035
	Mean accelerator pedal position	- 0.41	0.031
	SD speed	- 0.44	0.020
	Mean speed in 12 normal curves (mph)	- 0.47	0.012
	Mean speed in 6 sharp curves (mph)	- 0.40	0.036
Neuroticism	Time to complete (s)	- 0.39	0.040
	Mean speed (mph)	0.40	0.035
	Mean speed in 12 normal curves	0.42	0.025

Table 5-17. Associations between personality (five-factor domains measured using the NEO PI-R personality inventory) and driving behaviour measures

Higher agreeableness scores were associated with a slower driving style, with correlations in the opposite direction to those observed for neuroticism. The significant associations with agreeableness appeared to be driven by correlations in the *trust* and *modesty* facets (and to a lesser extent, correlations in the *straightforwardness* and *compliance* facets), such that higher *trust* scores and higher *modesty* scores were each associated with a slower driving style.

Neuroticism was positively correlated with three measures of driving behaviour (Table 5-17), all of which loaded on the dynamic driving factor identified earlier. The neuroticism facet *angry hostility* (tendency to experience anger and related states such as frustration and bitterness) was the main contributor to the overall domain correlations. *Angry hostility* itself was positively correlated with

other aspects of behaviour (higher speed, high engine speed, mean accelerator and brake pedal position, higher standard deviation of speed) that suggest a faster driving style.

Discussion

Perception of differences in available vehicle performance

The results supported hypothesis H5, that drivers can perceive differences in available vehicle responsiveness in naturalistic driving. However hypothesis H1, that drivers can perceive differences in available vehicle acceleration in naturalistic driving, was not supported: it seems that an acceleration difference of 8% was too small to cause a significant difference in self-reported perceived acceleration.

In Experiment blocks 2 and 3, there were significant differences in participants' magnitude estimates of perceived responsiveness in the high responsiveness versus low responsiveness conditions. The response delay in the low responsiveness condition was intentionally rather large, so it is perhaps not surprising that it was readily (though still not universally) perceived; nevertheless the result confirms that such differences can be perceived by drivers in naturalistic driving, a complex task when they have much else to process too. Perceiving the more modest 8% difference in available vehicle acceleration between the low and high acceleration conditions was clearly more challenging. There were small differences in participants' magnitude estimates of available vehicle acceleration in these two conditions in Experiment blocks 1 and 3, but although directionally appropriate they were not statistically significant. We can therefore conclude that drivers cannot directly perceive differences of 8% (over the speed interval most relevant to the test route, 30-50mph) in available vehicle acceleration in naturalistic driving. The acceleration difference between the low/high conditions must have been below the perceptual threshold for such differences. In the next chapter I shall describe further experiments to measure perceptual thresholds for acceleration difference. At this point, however, we can conclude that, for an electric vehicle to be perceived by drivers as having better acceleration performance than an equivalent ICE car, designers should aim for acceleration performance benefit that is somewhat higher than the low/high difference used in this experiment.

It is interesting to observe that both perceived acceleration and perceived responsiveness changed in response to any change in either vehicle acceleration or responsiveness: the perceptions were highly correlated. Thus although acceleration and responsiveness are *construed* as distinct attributes of vehicle performance (Chapter Three), in naturalistic driving, perceptions of them are less distinct: changes in either affect perceptions of both. It may be, however, that this is a reflection of the continuous nature of the driving in Experiment 2. Drivers might be better able to distinguish acceleration differences from responsiveness differences in driving that includes multiple standing starts, where response delays might be more readily experienced as different from changes in acceleration rate.

Feedback control: perception of vehicle performance affects driving behaviour

Participants' mean accelerator pedal depression over the course of the drive was higher in the low vehicle acceleration condition than in the high vehicle acceleration condition. Likewise, mean accelerator pedal depression was higher in the low responsiveness condition than in the high responsiveness condition. These findings support hypotheses H2 and H6 and provide empirical evidence that driving behaviour involves feedback control. In the IGD-driving model, whenever a change in the immediate driving situation leads to the reference level in the speed control loop increasing, the driver acts to reduce the discrepancy between her/her presently perceived speed and the new reference level, by depressing the accelerator pedal. Higher vehicle acceleration and/or responsiveness means that the control loop discrepancy will reduce more quickly in response to accelerator pedal depression, reducing how much depression is needed.

Carver and Scheier (1998) introduced a theory of affect based on feedback control. In their theory, positive affect arises when the rate at which a control loop discrepancy reduces is high – i.e. we feel positive emotions such as joy and elation when making rapid progress towards a goal. Conversely, negative affect arises when the rate of discrepancy reduction is low – when goal pursuit is thwarted. This theoretical perspective and the findings of Experiment 2 suggest one explanation for why fast acceleration when driving is often described by drivers as “fun” or

“exciting” - it provides more rapid rates of discrepancy reduction whenever a change in the immediate driving situation leads to an increase in the reference level in the speed control loop¹⁸.

Activity-level driving goals affect driving behaviour and perception of vehicle performance

Effect of goal condition on driving behaviour

The experiment found that dynamic driving (use of the accelerator pedal) changed in response to the activation of a journey goal to complete the route as fast as possible. The level of task difficulty was similar between the relaxed and time pressured conditions; in fact, the requirement to overtake several slower vehicles in the time pressured condition made this the more difficult condition. Thus if participants had been self-regulating their driving behaviour only on the basis of task difficulty, Risk Allostasis Theory would predict similar behaviour in both conditions, or even slower driving in the more difficult time pressured condition. In fact, drivers responded to the time pressure goal by attempting to drive faster, accelerating more quickly after each bend (and consequently needing to brake more severely on approaching the next bend). This supports the IGD-driving model, and the view that driving behaviour is not determined just by self-regulation aimed at a single goal, but rather results from inter-goal dynamics – i.e. it is the resultant of the combined influences of multiple goals, pursued simultaneously. I assume that in both relaxed and time pressured conditions, drivers had goals to complete the route (motivating higher use of the accelerator pedal) and goals to avoid harm (motivating lower use of the accelerator pedal). In the time pressured condition, however, the goal to complete the route *quickly* can be assumed to have been more highly activated and therefore more influential in affecting the resultant behaviour.

Differences in driver behaviour as a result of goal activation were also observed in another simulator experiment (Skippon et al., 2012) which used the manipulation of providing an attractive

¹⁸ High acceleration could also generate positive affect by contributing towards the pursuit of symbolic goals (Skippon et al., 2012). I shall explore the symbolism of vehicle performance and driving styles in Chapter Nine.

passenger of opposite gender, a situation where mating-related goals, including goals to signal personality traits, were activated.

Effect of goal condition on perception of vehicle performance

A somewhat mixed picture emerged of the effects of goal condition on perception of vehicle acceleration and responsiveness. In Experiment block 2, there was a significant goal condition \times responsiveness interaction: magnitude estimates of perceived responsiveness were lower in the time pressured condition when vehicle responsiveness was low, but when vehicle responsiveness was high (zero pedal delay) then perceived responsiveness was higher in the time pressured condition. This pattern supports the hypothesis that the different driving behaviours in the relaxed and time pressured conditions afford different opportunities to perceive available vehicle performance (H3(b)). Making more and faster accelerations during a drive should afford more opportunity to perceive the vehicle's responsiveness. Thus in the time pressured condition, participants had more opportunity to distinguish responsiveness differences.

In Experiment Block 1, the opposite pattern was observed: magnitude estimates of perceived acceleration were higher in the time pressured than the relaxed condition when available vehicle acceleration was low, but slightly lower in the time pressured condition when available vehicle acceleration was high. However the differences were rather small, and the goal condition \times vehicle acceleration interaction term was not significant. This can perhaps be attributed to the observation above that the difference between the low and high vehicle acceleration conditions was close to the perceptual difference threshold.

Effects of higher level goals/personality traits

Driver group

It was intended that the two driver groups would have different chronically active higher-level goals that would influence the relative activation of symbolic Activity goals, and hence their driving behaviour and the opportunities it afforded to perceive vehicle performance. However there

were no significant main effects of driver group, in any of the Experiment blocks, on driving behaviour or perception of vehicle acceleration or responsiveness.

Two possible explanations can be considered: either chronic activation of symbolic goals made no significant difference either to driving behaviours or perception of vehicle performance, or there was in fact little difference in chronic goal activation between the driver groups. The latter seems plausible, given that recruitment on the basis of fuel purchasing behaviour was at best a very indirect way to try to create inter-group differences in chronic activation of higher-level goals. The fuel purchasing behaviour used as an indication of performance orientation was perhaps not strongly enough associated with the symbolic goals I hoped would be chronically activated.

Personality traits

There was a very clear negative association between the five-factor trait agreeableness and faster, more dynamic driving behaviour. People who score highly on agreeableness take impact on other peoples' feelings into account when planning and choosing their behaviour. The results show that they also adopt slower, smoother driving behaviour with less acceleration and less braking. People who score lower on agreeableness are less inclined to take account of other peoples' feelings: the results show they adopt faster driving styles. Agreeableness was found to correlate negatively with accident risk by Cellar, Nelson, & Yorke (2000). Furnham and Saipie (1993) also found that Eysenck's psychoticism (related to, but not identical with, low agreeableness) was higher among drivers with convictions for traffic violations than those without. The findings of Experiment 2 are consistent with these studies if we assume that driving style mediates accident risk.

A review by Lajunen (1997) found that a number of studies have produced a mixed picture on the possible influence of neuroticism. In Experiment 2 there were moderate associations between neuroticism and faster, more dynamic driving. Supporting this is the finding that, although the trait extraversion as a whole did not correlate with aspects of driving style, the facet *positive emotions* was negatively correlated with measures of faster driving style. Thus people who experience more negative emotions, and people who experience less positive emotions, tended to drive faster. The correlations with neuroticism appear to have been mainly driven by the facet *angry hostility*.

High scores on conscientiousness were associated with slower, more careful driving styles. However the effects were weaker than those for agreeableness. Sumer, Lajunen, and Ozkan (2005) found that conscientiousness correlated negatively but weakly with self-reported Errors, Lapses and Violations as measured by the Driver Behaviour Questionnaire (Reason, Manstead, Stradling, Baxter, and Campbell, 1990). Arthur and Graziano (1996) found that it correlated negatively with accident risk.

Two driving behaviour measures correlated with openness: average clutch position correlated positively, and time in the opposite lane during the first overtaking manoeuvre correlated negatively. This is an idiosyncratic combination and I can offer no useful interpretation, beyond the possibility that it may reflect a chance result.

No measures of driving style correlated with extraversion. Initially this is perhaps surprising, but it seems that two facets of extraversion, *excitement seeking* and *positive emotions*, had oppositely-directed associations: *excitement seeking* was (weakly) positively associated with faster driving, while *positive emotions* was negatively associated. It appears that the lack of association between extraversion and driving can be accounted for by oppositely-directed correlations with these facets. Sumer et al. (2005) found a weak correlation between extraversion and accident risk. Other studies (Ulleberg, 2002; Ulleberg & Rundmo, 2003; Rimmo & Alberg, 1999; Sumer, 2003; Jonah, 1997) have found that sensation seeking (related to the extraversion facet *excitement seeking*) correlated with risky driving behaviours. The results of Experiment 2 are consistent with these findings.

Figure 5-19 summarises the relationships between personality traits and driving behaviour as found in the experiment. The results show that driving behaviour is indeed related, at least in part, to personality. The findings build on previous studies, by relating driving behaviour, measured directly in driving simulation experiments, to the FFM, using a modern, comprehensive measure of the latter. Few previous studies have related personality traits directly to driving behaviour, as opposed to more distal measures.

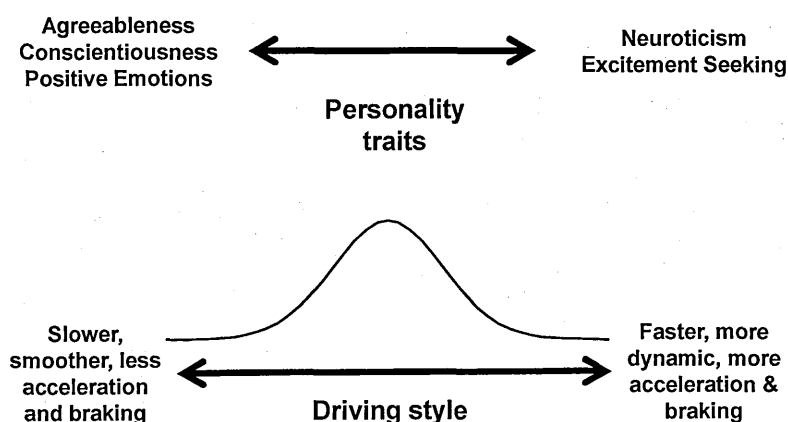


Figure 5-19. Summary of significant relationships between personality traits and driving behaviour

It is clear that faster, more dynamic driving is associated to some extent with high neuroticism, high *excitement seeking*, low agreeableness and low conscientiousness. The more any of these are combined, the more likely it is that the person will tend to have a more dynamic driving style that will potentially afford greater opportunities to perceive available vehicle performance. Slower, smoother driving is associated with the opposite combination of personality traits: low neuroticism, low *excitement seeking*, high agreeableness and high conscientiousness. Of course there are other influences on driving behaviour in the model developed in Chapter Four. The observed correlations with personality in this experiment tended to be in the range $r = 0.4$ to 0.5 : so while personality influenced driving behaviour, it by no means fully determined it.

Given the large number of variables it is reasonable to expect some correlations might have occurred by chance, so some caution is needed in interpretation. Where there were multiple associations (such as those between agreeableness and measures of driving style) we can be confident of real effects. On the other hand the weak correlations between openness and two measures of driving style may best be explained as chance associations.

This aspect of Experiment 2 involved a correlational design, so it is not possible to draw the formal conclusion that these aspects of personality *cause* faster and slower driving styles. However, given

the stability of personality traits in adulthood (McCrae & Costa, 2003), the reverse direction of causality, that driving style causes these aspects of personality, seems implausible.

Conclusions

The IGD-driving model is complex, and Experiment 2 was able to test only certain key aspects of it. Nevertheless the experiment provides empirical evidence supporting it.

Firstly, the experiment shows that driving behaviour is affected by personality traits, and also by the activation of journey-specific goals.

Secondly, the experiment provides evidence that perception of differences in vehicle performance occurs more readily when driving behaviour affords more opportunities to perceive it – the responsiveness difference was perceived as larger in the time pressured condition, when drivers adopted more dynamic driving behaviour, than in the relaxed condition.

Thirdly, the experiment shows that ordinary (non-expert) drivers can perceive some differences in vehicle performance (responsiveness) during naturalistic driving. Given the complexity of the driving task, the volume of information to be perceived and processed moment-by-moment, and the observation in the previous chapter that often the same physical acceleration can be experienced from a vehicle with lower performance by depressing the accelerator pedal more (except when already at full pedal depression), it was not necessarily appropriate to assume this would be the case.

However there are limits to drivers' abilities to perceive performance differences. Participants had little difficulty perceiving the large responsiveness difference in the experiment, but the more modest difference in available acceleration appears to have been below the perceptual difference threshold. In Chapter Six I shall measure perceptual difference thresholds for acceleration in driving, drawing on the methods of psychophysics. It is sufficient here to suggest that designers of electric vehicles wishing drivers to perceive them as having better performance than conventional ICE cars, will need to provide acceleration differences somewhat higher than the 8% (over the 30-50mph speed range) used in this experiment.

In Chapter Three I raised the possibility of *implicit learning* of vehicle performance, based on the importance participants in Study 1 attached to constructs of confidence in ability to accelerate and overtake. Small differences in vehicle performance, that may not be perceived directly in normal driving, may nevertheless contribute incrementally to the driver's mental representation of his/her vehicle's performance, and so indirectly to the degree of confidence he/she feels in undertaking driving tasks such as overtaking. This will be explored experimentally in Chapter Seven.

Acknowledgements

Experiment 2, and Experiments 3, 4, 5, and 6 described in the following chapters, were designed by the author and conducted with staff of the TRL DigiCar facility, led by Dr. Nick Reed and facility manager Lena Weaver. The author conducted the analyses.

Material from this chapter has been published in an edited collection (Skippon, Reed, Luke, Robbins, Chattington, & Harrison, 2010).

Chapter Six. Difference thresholds for perception of maximum available vehicle acceleration

Measurement of difference thresholds for vehicle acceleration

Controlling for driving behaviour

Experiment 2 established that drivers can perceive some differences in the dynamic performance of a vehicle in naturalistic open-road driving, but also that a difference in available vehicle acceleration of 8% was below the perceptual difference threshold. It also showed that perception of differences in vehicle performance occurs more readily when driving behaviour affords more opportunities to perceive it, and that driving behaviour is affected by personality traits, and by the activation of journey-specific goals (in the model developed in Chapter Four, these effects are described by equation (4-17)). Naturalistic driving experiments, even in the controlled conditions of a driving simulator, are therefore subject to confounding effects that make it difficult to measure difference thresholds (i.e. the amount of change required to produce a difference that is just noticeable by a driver) for performance attributes. Difference thresholds, however, are exactly what the designer of an EV, seeking to offer a dynamic performance benefit, needs to know. Extra performance adds to costs, and in the case of BEVs reduces the driving range available from the vehicle: so the designer needs to find an optimum that provides a noticeable, but not extravagant benefit.

However if, instead of naturalistic driving, we consider a more simple case, a single maximum pedal depression acceleration from a fixed initial speed and gear, then all the variability due to driving goals, driver personality and driving situation is controlled for. Each of the likelihood functions in equation (4-17) is therefore unity in the experimental condition, and zero for all other conditions, so equation (4-17) reduces to:

$$p(A') = 1 \text{ and } A' = VA_{\max}(\text{ISLG}) \quad \dots(6-1)$$

This is the basis of the experimental paradigm for the experiments in this chapter: they are based on participants making a maximum pedal depression acceleration from a fixed initial speed and gear.

Psychophysical scaling

Psychophysics is the study of the relationships between physical stimuli and the psychological sensations or perceptions that result from them. It is particularly concerned with questions of scaling (how far the psychological sensation changes for a given change in the physical stimulus) and perceptual thresholds (what difference in stimulus is just noticeable as a difference in psychological sensation). Psychophysics distinguishes two types of thresholds for the perception of stimuli: the *absolute threshold*¹⁹ (*RL*) which represents the absolute minimum value of the stimulus where it is first detectable by a person’s perceptual system, and the *difference threshold* (*DL*) which represents the amount of change in a stimulus required to produce a *just noticeable difference* in the sensation (Gescheider, 1997).

The size of the psychological sensation ψ , evoked by the stimulus, is a function of the size of the physical stimulus, ϕ , but there is generally not a linear relationship between them.

$$\psi = f(\phi) \qquad \dots(6-2)$$

The relationship depends on the specific nature of the sensory and perceptual systems involved (visual, auditory, vestibular, etc.). Modern formulations such as Borg’s (1998) more complex form of Stevens’ Power Law (Stevens, 1975) suggest modality-specific power law relationships between them:

$$\psi = a + c(\phi - b)^n \qquad \dots(6-3)$$

¹⁹ RL stands for the German Reiz Limen, and DL for Differenz Limen. The early psychophysicists who developed these ideas, Weber and Fechner, were both German, and the field has retained their original notation for these constructs.

Where a, b and c are constants. Equation (6-3) has been found empirically to fit many types of sensation-stimulus relationship, with different values of the exponent n: 0.2 to 0.4 for brightness, 0.4 to 0.7 for loudness, 2.0 for speed (Borg, 1998).

There is also, typically, a relationship between the difference threshold, DL, and the magnitude of the stimulus (Gescheider, 1997):

$$DL = k \varphi \quad \dots(6-4)$$

where k is a constant. Equation (6-4), known as Weber's Law, has been found to hold for a wide range of stimuli except close to the absolute thresholds. It predicts that the difference threshold for a stimulus will grow as the magnitude of the stimulus grows. Thus the difference in vehicle acceleration that would be just noticeable by a person should be higher, the higher the initial value of acceleration. Since the acceleration rates that can be produced in different initial speed and gear conditions are substantially different, this suggests that difference thresholds may vary with initial speed, gear and load conditions.

The method of paired comparisons

The method of paired comparisons (David, 1963; Gescheider, 1997; Guilford, 1954; Torgerson, 1958) has become the established means to measure difference thresholds. In this method, participants experience a pair of stimuli, S and C, and are asked to judge which is the larger. In the experiments in this chapter, participants made pairs of maximum pedal depression accelerations in which VA_{\max} differed, and made judgments as to the drive on which perceived acceleration was highest.

According to Thurstone (1927), repeated instances in which the same stimulus φ is applied to the senses result in a distribution of sensations ψ , because of momentary fluctuations in the state of the sensory and perceptual systems. It is assumed that the sensations are distributed normally on the sensation continuum. Such distributions are known as *discriminal dispersions*. Figure 6-1 shows what happens when a participant experiences a number of stimulus S / stimulus C pairs. The participant's responses to stimuli S and C form two *discriminal dispersions* on the sensation

continuum, with means $\overline{\psi}_S$ and $\overline{\psi}_C$ respectively. The size of the discriminial difference, $\psi_C - \psi_S$, varies from pair to pair as ψ_C and ψ_S are each drawn randomly from their respective discriminial dispersions. Because the discriminial dispersions overlap, for any given pair of stimuli, there is a certain probability p that ψ_C will be judged greater than ψ_S , and a probability $(1 - p)$ that ψ_C will be judged lower than ψ_S .

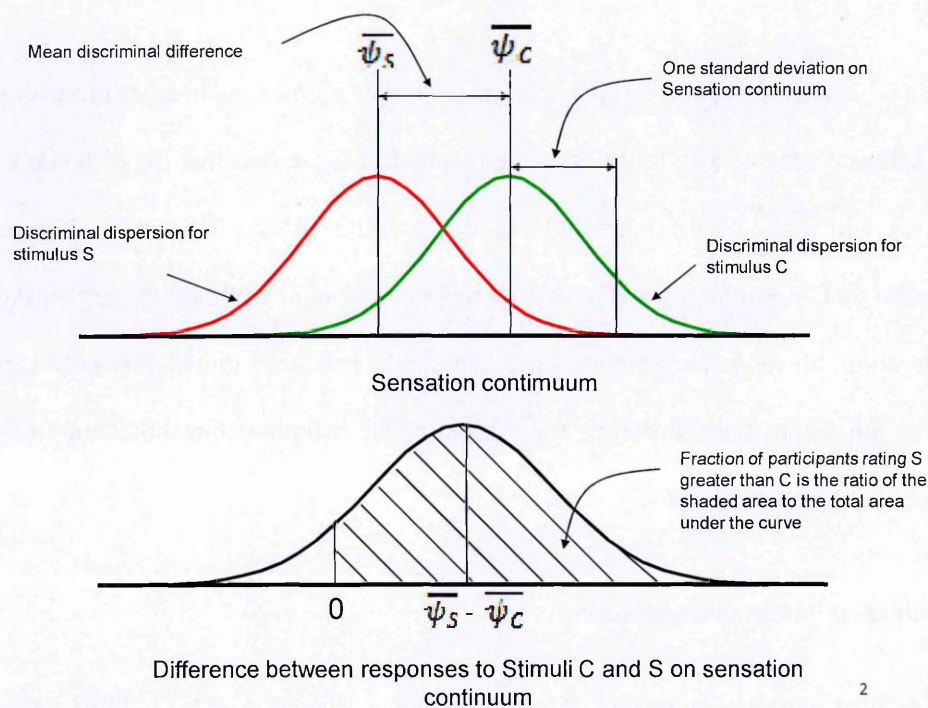


Figure 6-1. Method of paired comparisons: Each pair of stimuli is drawn from the respective distributions of the individual stimuli. The fraction of participants rating one greater than the other depends on the distance between the means of the individual distributions, on the sensation continuum ψ

In a paired comparison experiment the fraction of participants rating stimulus S greater than stimulus C is measured. When the two stimuli are equal, the discriminial dispersions overlap completely, and stimulus S will be rated greater than stimulus C on 50% of comparisons (and vice-versa). When there is a difference in the stimuli, the fraction of times that stimulus C is judged to be greater than stimulus S will be determined by the degree to which $\overline{\psi}_S$ and $\overline{\psi}_C$ differ. Thus the fraction can be used as a measure of $\overline{\psi}_S - \overline{\psi}_C$.

Since the differences between ψ_S and ψ_C are themselves distributed normally, the fraction of paired comparisons can be expressed as a z score, z_{CS} . Thurstone's Law of Comparative Judgment (Thurstone, 1927) gives the relationship between $\bar{\psi}_S - \bar{\psi}_C$ and z_{CS} :

$$\bar{\psi}_C - \bar{\psi}_S = z_{CS} \sqrt{(\sigma_{\psi_C}^2 + \sigma_{\psi_S}^2 - 2r_{\psi_S\psi_C}\sigma_{\psi_C}\sigma_{\psi_S})} \quad \dots(6-5)$$

Where the σ terms under the radical refer to the standard deviations of the discriminial dispersions for stimuli C and S respectively, and the r term under the radical is the degree of correlation between ψ_S and ψ_C . The terms under the radical cannot generally be measured experimentally, as experimenters do not have direct access to the sensation continuum, which is an internal mental process. However in many circumstances equation (6-5) can be simplified by making appropriate assumptions. For example, assuming that the discriminial dispersions for ψ_S and ψ_C are equal and uncorrelated, equation (6-5) simplifies to:

$$\bar{\psi}_C - \bar{\psi}_S = z_{CS} \sqrt{2} \quad \dots(6-6)$$

where for simplicity the scale unit of the sensation continuum is arbitrarily set to equal one standard deviation. Under these assumptions, the difference in sensations, on the sensation continuum, can be calculated directly from the fraction of responses in a set of paired comparisons.

The method of paired comparisons, then, provides a way to measure differences on the sensation continuum ψ that correspond to differences on the stimulus continuum ϕ . To determine the difference threshold, DL, we require the difference in stimulus intensities that produces a just noticeable difference in sensation. Consider an experiment in which one member of a pair of stimuli has a standard intensity, ϕ_S , and the intensity of the other member of the pair, ϕ_C , is varied. When $\phi_S = \phi_C$, the fraction of responses in which ϕ_C is rated greater than ϕ_S will be 50%, and Z_{CS} will be zero. As ϕ_C is increased, the fraction of responses will increase and asymptotically approach 100%. A reverse pattern will occur if ϕ_C is reduced relative to ϕ_S . The fraction of responses will follow a cumulative normal distribution, as shown in Figure 6-2.

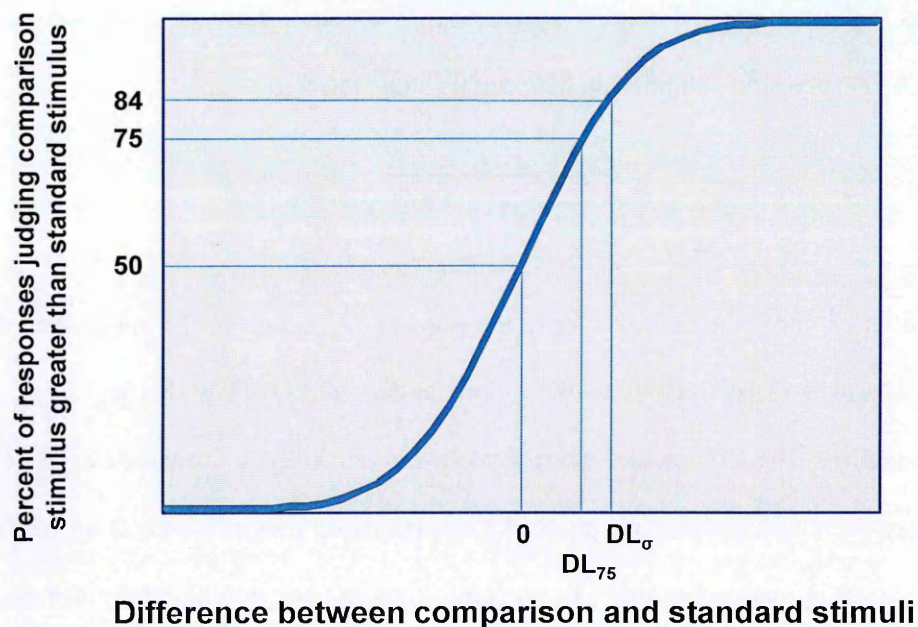


Figure 6-2. Definitions of Difference Threshold, DL

In classical psychophysics, the difference threshold was defined as the difference in stimulus intensity that results in the comparison stimulus being judged greater than the standard stimulus on 75% of paired comparisons (Gescheider, 1997). This is designated DL_{75} in Figure 6-2. An alternative definition is that the difference threshold is the difference in stimulus intensity at one standard deviation of the cumulative normal distribution, i.e. when the z score is unity or when the comparison stimulus is judged greater than the standard stimulus on 84% of paired comparisons. This is designated DL_{σ} in Figure 6-2. DL_{σ} is larger than DL_{75} (the values of DL quoted in Chapter 4 from MacNeilage et al. (2007) were DL_{σ} values).

DLs defined in either of these ways are statistical quantities, based on the outcomes of multiple paired comparisons. We cannot have direct access to any individual's sensation continuum, or to what constitutes a just noticeable difference on it. These approaches, however, enable us to capture something meaningful about how small a difference in stimulus intensity will be noticed reliably by a sample of people.

Based on the above discussions one can formulate an experimental design to measure difference thresholds for vehicle acceleration. Participants experience pairs of acceleration manoeuvres that

are the same in every respect except $VA_{\max}(\text{ISLG})$, the maximum available vehicle acceleration (in that initial speed, load and gear condition). One acceleration manoeuvre in each pair has a standard value of $VA_{\max}(\text{ISLG})$, and the other has a different, comparison value. The fraction of pairs in which the comparison $VA_{\max}(\text{ISLG})$ is judged by participants to be greater than the standard $VA_{\max}(\text{ISLG})$ is measured. This is repeated for a number of different comparison $VA_{\max}(\text{ISLG})$ values. A cumulative normal distribution can then be fitted to the data, and used to calculate DL_{75} or DL_{σ} in the manner shown in Figure 6-2²⁰. This design is particularly suited for implementation in a driving simulator, since the performance of the simulated vehicle can be changed between drives by a simple alteration to the vehicle dynamics model²¹.

Combining cues for perception of acceleration in driving

The discussion above has assumed that a single stimulus modality is being sensed. However as we saw in Chapter 4, acceleration can be sensed through visual, auditory, vestibular and other cues from multiple modalities, and perceptual processes then combine the information contained in all of these cues. A naïve hypothesis would be that difference thresholds reduce as more cues are added, providing more information. However as we saw in Chapter 4, a Bayesian cue-combination model would suggest that, if we assume that cues from different modalities are weakly coupled, then the participant's estimate of acceleration, $VA_{\max}(\text{ISLG})$, will be a weighted average of estimates based on visual cues ($VA_{\max V}$), vestibular cues ($VA_{\max O}$), auditory loudness cues ($VA_{\max L}$), auditory frequency cues ($VA_{\max F}$) and the Bayesian prior $VA_{\max P}$:

$$\widehat{VA_{\max}(\text{ISLG})} = W_V VA_{\max V} + W_O VA_{\max O} + W_L VA_{\max L} + W_F VA_{\max F} + W_P VA_{\max P} \quad \dots(6-7)$$

²⁰ An alternative approach is to fit a Bradley-Terry-Luce Logit model to the data. The two distributions are very similar in form so there is little advantage in choosing one over the other; I have chosen the approach that is consistent with the psychophysics literature.

²¹ A potential issue, however, is that the driver must hold the magnitude of the stimulus from the first drive in memory until the second has been experienced: the memory of the second stimulus will always be more recent than that of the first. This may lead to order effects that need to be controlled for.

This model enables certain predictions to be made. Firstly, if the reliability of a sensory cue is degraded in some way (for instance, a reduction in image contrast when driving in fog) then it will have relatively less weight in the perceptual estimate of acceleration (and the Bayesian prior will have relatively more weight). Secondly, if individual sensory cues are inconsistent, then the perceptual estimate will be a weighted average. In normal driving, cues produced by genuine motion through the environment can generally be expected to be consistent. However in a driving simulator, cues are produced by discrete cueing systems (visual, auditory and motion), which may be inconsistent to some degree. Cue inconsistencies may also occur because the association between auditory cues and acceleration must be learnt, not innate. If the acceleration-auditory sensation association on a particular drive is different from the learnt one, this will lead to erroneously higher or lower estimates. This may occur, for instance, when driving a different car, or again, in a driving simulator.

Research questions

Since Weber's Law (equation (6-4)) suggests that difference thresholds for acceleration may vary with initial speed, gear and load conditions, the key purpose of the experiments in this chapter is to determine difference thresholds for maximum vehicle acceleration, and how these vary with initial speed, load and gear conditions. Study 1 showed that drivers construe acceleration from standing start, and mid-range acceleration, as different attributes of dynamic performance, so I included two ISLG conditions to reflect these: acceleration from 0-20 mph in 1st gear, and acceleration from 30-50mph in 3rd gear. In addition, I included acceleration from 50-70mph in top gear (reflecting, say, overtaking on a multi-lane road), to cover the full range of acceleration conditions likely to be encountered in normal driving.

My initial intention was to carry out these experiments in the TRL DigiCar driving simulator. However as noted above, there might be inconsistencies between acceleration cues from the different cueing systems in a driving simulator, that could influence the validity of the results. In Experiment 3 I therefore investigated the consistency of difference thresholds for mid-range acceleration, measured in the simulator with different cue combinations, testing the hypothesis that

variations in difference thresholds as a function of cue combinations would not be predicted by a naïve additive model but would depend on cue consistency as predicted by a Bayesian model.

The opportunity was also taken to investigate two supplementary questions. Since the findings of Study 1 suggested a possible role for implicit perception of acceleration, it seemed plausible that perception of acceleration differences close to the difference threshold might have an implicit component, but that, as the difference in available vehicle acceleration increased above the difference threshold, participants would become consciously aware of the difference, and this would be reflected in increasing confidence in their judgments. Experiments 4 and 5 therefore tested whether confidence in judgments increased with acceleration difference. In addition, participants in Experiments 4 and 5 were asked to report on what sensory cues they thought they had actually used in the experiment. This enabled independent tests of my assumption that multiple sensory cues are involved in the perception of acceleration difference.

Experiment 3: Effect of sensory cue combination on perception of acceleration difference

Method

Driving simulator and experimental route

Experiment 3 was carried out using the TRL DigiCar driving simulator, described in Chapter Five. The experimental route was a long and relatively straight section of simulated UK rural dual carriageway, which could be negotiated safely at speeds up to 70mph without deceleration at any point. A simulated overtaking target vehicle was present in the simulated environment, in a position ahead of the simulator vehicle. The speed of the target vehicle was constant, at the same speed as the initial speed of the simulator vehicle at the start of the acceleration manoeuvre. In the majority of drives the participant caught up with and passed the target vehicle by the time the required target speed was reached. Figure 6-3 shows the forward view of the route, at the start of the acceleration manoeuvre, with the target vehicle visible ahead in the distance.

The simulator vehicle began each drive in the right hand lane, so that the entire drive and acceleration manoeuvre could be completed with minimal steering. This prevented any disorientation or distraction of the participant that might result from the absence of lateral force simulation in the DigiCar simulator when carrying out lateral displacement manoeuvres such as lane changing.

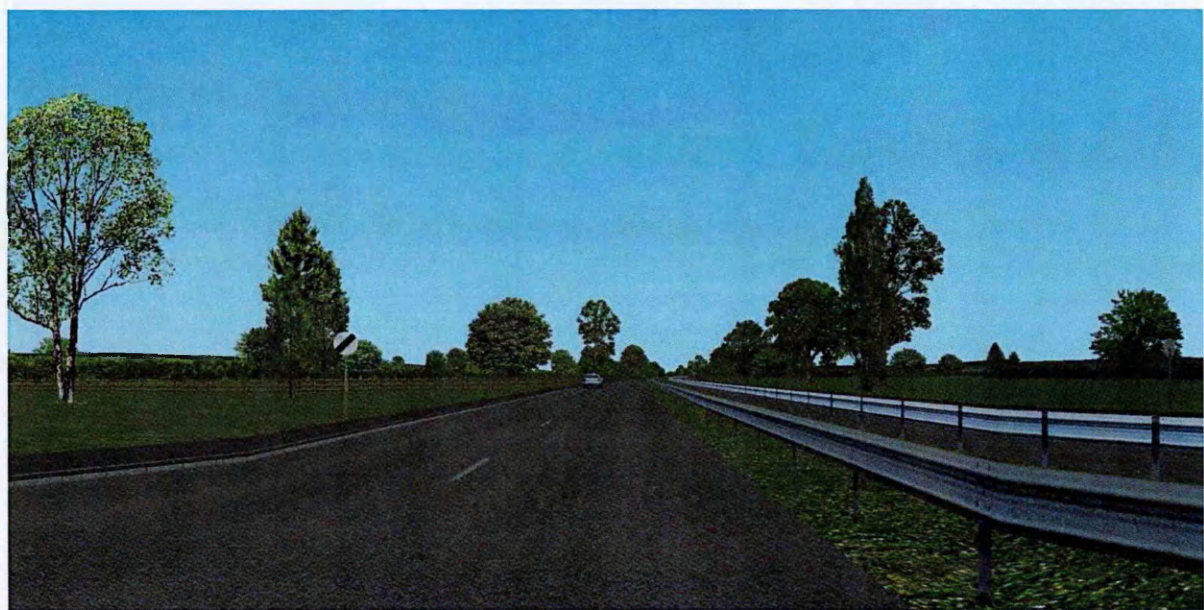


Figure 6-3. Experimental route as seen at start of acceleration manoeuvre. Overtaking target vehicle visible in left lane ahead

Participants

50 participants completed Experiment 3: 25 were male and 25 female. All had a full UK driving licence, and a large majority (47) had more than 5 years driving experience. The mean age of the sample was 38.6 ± 9.6 years. The mean number of years of driving experience was 19.7 ± 9.3 . All participants drove more than 8,000 miles per year. The mean annual mileage of the sample was $14,061 \pm 12,261$ miles. Potential participants who drove diesel vehicles were excluded, since the simulated vehicle had the characteristics of a car with a spark-ignition (gasoline fuelled) engine. Those who worked in advertising, marketing, market research, car or motoring industries, petroleum industry, public relations, journalism, TV or media, were also excluded, again for reasons of sponsor confidentiality.

Independent variable: sensory modality

The independent variable was the sensory modalities available to convey acceleration cues to the participant. Three modalities were represented in the DigiCar simulator: Visual, Sound and Motion. The experimental route provided two types of visual acceleration cue. The first type of cue was optic flow of roadside features such as trees and the roadside crash barrier, and the central road markings, which moved outwards from the centre of the field of view with angular velocities which gave cues to speed. The second type of cue was the target vehicle, which grew in angular size as it was approached. The visual environment also contained a horizon that offered a visual tilt cue. The sound system conveyed acceleration information in two ways: through the frequency of the engine sound, and through loudness. Increasing speed is associated with higher engine frequency and loudness. The motion system was able to convey acceleration information using a tilt cue, corresponding to the tilt backwards of a vehicle at the beginning of an acceleration (and the equivalent tilt forwards on braking). There was no system of tilt co-ordination so it was not possible to provide a vestibular acceleration cue.

There were four different sensory modality conditions:

- Visual only
- Visual and Motion
- Visual and Sound
- Visual, Motion and Sound

Independent variable: Maximum Available Vehicle Acceleration

Maximum Available Vehicle Acceleration (VA_{max}) was modified by specifying different levels of a variable, *engine yield*, in the simulator's vehicle dynamics model. Adjusting the engine yield variable simulated different levels of engine output and caused the simulated vehicle to move through the simulated environment with higher apparent acceleration.

Two different VA_{max} conditions were used in Experiment 3. The first (VA_0) was a baseline condition in which *engine yield* was maintained at the default setting of the system, which

simulated the dynamics of a 1.6l Renault Megane. For the second, the value of engine yield was adjusted to deliver a maximum acceleration over the required speed range of 9% higher than baseline (VA9).

Experimental design

In Experiment 3 all drives involved mid-range acceleration, from 30mph to 50 mph. Each participant completed 16 drive pairs, 4 in each sensory modality condition. Within the group of 4, 2 drives had the order VA0 first, then VA9 second, the other two had the opposite order. Constraints on the time taken to change between sensory modality conditions meant that all 4 drive pairs within the same sensory modality condition were carried out in sequence for each participant. However, the order of sensory modality conditions, and the sequence of drive pairs with a sensory modality condition, was counterbalanced across the participant pool.

Dependent variable: frequency of correct pair-wise judgments

Participants completed pairs of drives in succession. After each pair, the participant made a pair-wise judgment as to the drive in which the vehicle accelerated fastest. Individual judgments were categorised as correct or incorrect. The *percentage of correct responses* for each VA_{max} pair was calculated by totalling responses between participants.

Simulator outputs

Three simulator outputs, logged at 20 Hz, were recorded:

- *Gear*: the gear selected
- *Accelerator Pedal Depression*: the position of the accelerator pedal, from 0.0 (no depression) to 1.0 (fully depressed)
- *Speed*: the longitudinal ground speed of the simulated vehicle relative to the simulated environment (in mph)

Gear and *Accelerator Pedal Depression* were logged to act as a validity filter, enabling checking of the data and rejection of individual drives if the experimental conditions had not been met (for

instance, if the participant delayed depressing the accelerator pedal significantly after receiving the “go” signal). *Speed* was used to calculate the actual acceleration rate produced in each drive.

Procedure

On arrival at TRL participants completed a consent form and short demographics questionnaire. Participants then completed one familiarisation drive, using the same familiarization route as Experiment 2, to enable them to quickly become comfortable with the simulated environment and car controls. Immediately afterwards, they were verbally briefed on how to carry out the experiment, and experienced six practice pairs of drives.

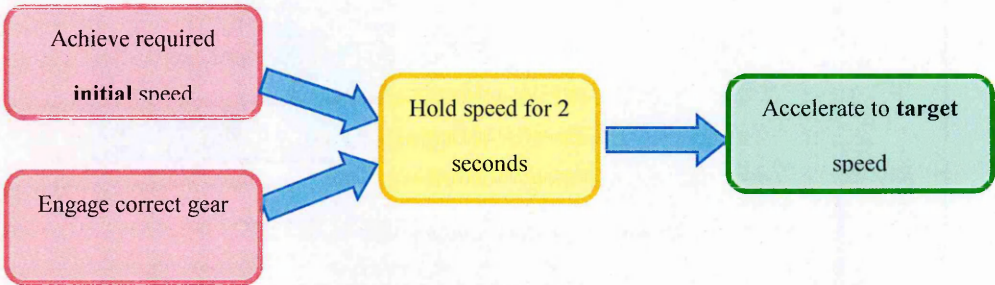


Figure 6-4. Procedure for individual drives

The procedure for individual drives is shown in Figure 6-4. Participants started each individual drive with the simulator vehicle stationary in the right hand lane. They accelerated to the required initial speed and engaged the required gear. The visual display indicated the required gear and speed, the current gear, and whether to speed up or slow down to attain the required initial speed (Figure 6-5).

Once the required initial speed had been reached the visual display indicated the message “Prepare to accelerate to (target final speed)”. Once the required initial speed had been maintained continuously for 2 seconds (within ± 5 kph (3.13 mph) the visual display indicated the instruction “GO”. At this point participants depressed the accelerator pedal fully. This process ensured that experimental drives started in the correct gear and from a steady-state initial speed. Once the target final speed had been reached, the visual display changed to indicate the message “Target Speed Reached”. At this point the participant slowed the simulated vehicle to a halt.

After each pair of drives, participants were asked over the intercom “on which drive did the vehicle accelerate the fastest, the first drive or the second?”

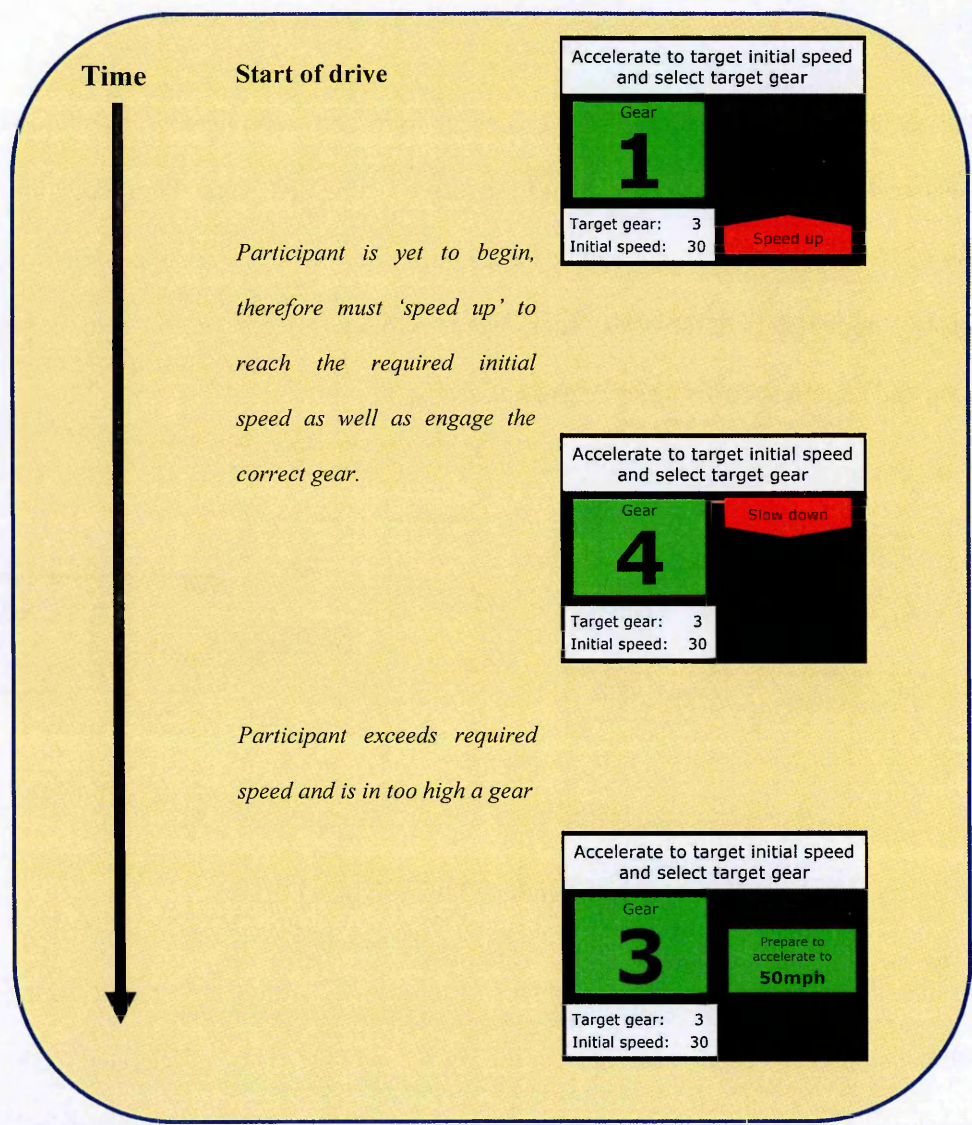


Figure 6-5. Example of Visual Display sequence for drive in Experiment 3 (3rd gear, 30mph to 50 mph acceleration)

Results

Figure 6-6 shows the percentage of correct and incorrect responses for each of the four different sensory modality conditions. The frequency of correct responses was larger in the Visual only condition than any of the other three. This result contradicts the naive hypothesis that acceleration difference would be less readily perceived when less sensory modalities were available. The

differences between correct and incorrect responses were statistically significant for all four conditions (X^2 test, $p < 0.05$ criterion; Table 6-1).

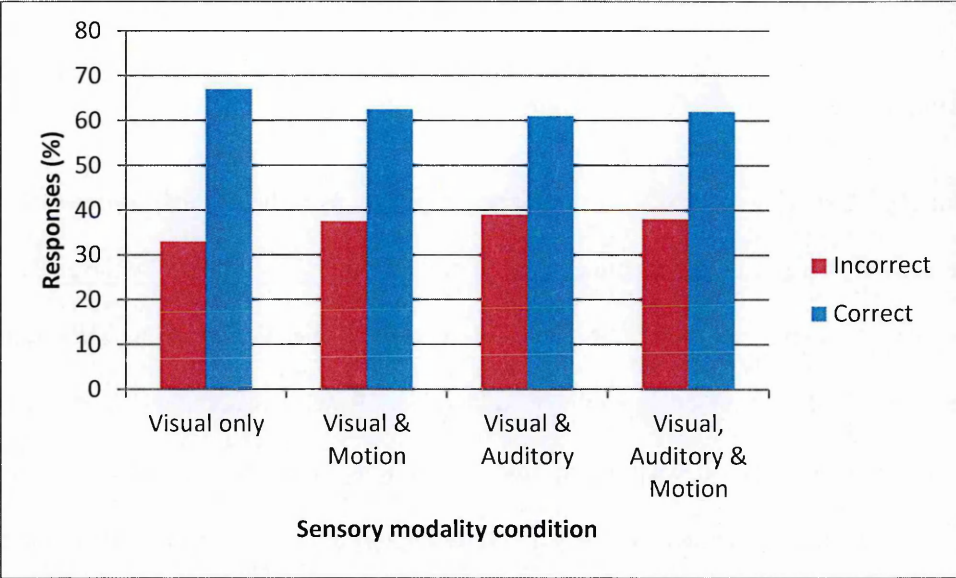


Figure 6-6. Perception of acceleration difference using different combinations of sensory cues: Correct and Incorrect response rates

Sensory modalities	Correct responses (%)	Incorrect responses (%)	X ² (1)	p	DL ₇₅ relative to standard stimulus VA0 (%)
Visual only	67	33	11.56	0.001	13.9
Visual & Motion	62.5	37.5	6.19	0.013	19.1
Visual & Auditory	61	39	4.84	0.028	20.1
Visual & Auditory & Motion	62	38	5.76	0.016	19.4

Table 6-1. Experiment 3: Perception of acceleration difference using different combinations of sensory cues: X^2 tests and difference thresholds

Table 6-1 also shows the difference thresholds (DL_{75}) for each cue combination, calculated by assuming that the data lie on a cumulative normal distribution. The DL_{75} value for the Visual Only condition was slightly lower than that for the other three.

Discussion

The results of Experiment 3 do not support the naive hypothesis, that difference thresholds decrease as more sensory cues become available: the opposite was found to be the case. The results can, however, be explained using the Bayesian model of cue combination. The results for the presence/absence of motion cueing can be understood if we assume that the motion cue was assigned zero weight when it was absent, and some finite weight when present. The motion cue signal represented a cue for lower acceleration than the visual cue, because of the limitations of the motion system described in the method section. The Bayesian cue combination model predicts that an inconsistent, lower acceleration estimate from the vestibular system would reduce the overall, multi-sensory perception of acceleration, as observed. A similar argument can be advanced for the auditory cues. While the auditory frequency cue (representing engine speed) was realistically simulated, the results suggest that the auditory loudness was an inconsistent cue, signalling lower acceleration than the visual cue. This is entirely plausible, and would result if the auditory signals were quieter in the simulator than those participants had learned to associate with acceleration in their usual vehicles.

The implication was that the auditory and motion cues for acceleration in the driving simulator were somewhat inconsistent with the visual cues. This suggested that the simulator did not have *absolute* validity for perception of acceleration and hence difference thresholds. Accordingly, in Exper 5, the absolute difference threshold for mid-range (30-50mph) acceleration was measured using a real vehicle on a test track. However it was not feasible to measure difference thresholds for 50mph-70mph accelerations in this way, because of safety considerations and a 60mph speed limit for drivers without specialist training on the TRL test track. Neither was it feasible to perform an accurate test track experiment for the 0-20mph speed range, because of the large contribution to variance that results from drivers having to control the vehicle clutch as well as the accelerator pedal. Therefore a pragmatic approach was taken. Since it seems reasonable that the simulator had

relative validity for acceleration perception in different speed ranges (the inconsistencies being similar across these conditions), in Experiment 4 I measured the *relative* difference thresholds for accelerations in all three different speed ranges of interest. I could then use the ratios between them, and the absolute value for 30-50mph accelerations from Experiment 5, to estimate the absolute difference thresholds for 0-20mph and 50-70mph accelerations.

Experiment 4: Relative difference thresholds for acceleration in three different speed ranges

The primary aim of Experiment 4 was to measure the difference thresholds for acceleration in the three speed ranges, relative to each other. The opportunity was also taken to address two supplementary questions: (1) whether, as the difference in available vehicle acceleration increased above the difference threshold, participants became consciously aware of the difference, reflected in increasing confidence in their judgments; (2) what sensory cues participants thought they had actually used in making their judgments.

Method

Experiment 4 was also carried out in the TRL DigiCar simulator, using the same basic method as Experiment 3. However in Experiment 4 there was an additional independent variable, Initial Speed and Gear (ISG), and additional levels of VA_{max} to generate more data points from which to determine difference thresholds.

Independent variables

Table 6-2 summarises the three ISG conditions. In ISG 1, acceleration began from 2mph rather than 0mph, to reduce errors arising from drivers needing to engage the clutch to start the simulated vehicle moving.

Four different VA_{max} conditions were used in Experiment 4: a baseline condition (VA_0) in which *engine yield* was maintained at the default setting of the system, as in Experiment 3; and three conditions in which the value of engine yield was adjusted to deliver a maximum acceleration over

the required speed range of 3% higher than baseline (VA3), 6% higher than baseline (VA6) or 9% higher than baseline (VA9).

ISG condition	Gear	Initial Speed		Target Speed		Mean (SD) time to reach target speed (s)	Mean acceleration (ms ⁻²)
		(mph)	(ms ⁻¹)	(mph)	(ms ⁻¹)		
ISG 1	1 st	2	0.9	20	8.94	2.65 (0.29)*	3.20*
ISG 2	3 rd	30	13.41	50	22.35	8.31 (0.27)*	1.07*
ISG 3	4 th	50	22.35	70	31.29	11.72 (0.57)*	0.76*

* Mean times and mean accelerations for all drives in baseline Vehicle Acceleration condition (VA0). SD = standard deviation.

Table 6-2. Initial Speed and Gear (ISG) conditions

Dependent variables

Frequency of correct pair-wise judgments was the main dependent variable, as in Experiment 3; and the same simulator outputs were recorded for the same purposes. In addition, after each drive pair participants were asked to estimate their degree of confidence in the accuracy of their judgment, using a 10-point scale with two verbal anchors, 1 = no confidence and 10 = total confidence.

Self-report of perceptual cues used to make judgments

On completion of the simulator session participants completed a brief questionnaire in which they rated how far each of nine possible cues had influenced their judgments about in which of each pair of drives the vehicle had accelerated the fastest. The possible cues were:

- Distance to the lead vehicle
- Time taken to reach the lead vehicle

- Passing trees, signposts, etc.
- Passing road markings
- Changes in the loudness of engine noise
- Changes in the pitch of engine noise
- Physical sensation and feedback from the car
- Monitoring the rev counter
- Monitoring the speedometer

Participants were asked to rate how much influence each of these had on their judgments, using a 6 point scale with verbal anchors for each point (None, Very little, Little, Moderate, Much, Very Much).

Experimental design

The experiment used a within-participants design in which each participant experienced 24 pairs of drives. In each pair ISG was constant. One drive of the pair was always the baseline VA_{\max} condition (VA0); in the other drive, VA_{\max} could vary (VA0, VA3, VA6, or VA9). Thus there were 3 (ISG) x 4 (VA_{\max} pair) = 12 conditions. To control for order effects, each condition was repeated with the pair order reversed, making 24 pairs in total.

Procedure

The procedure was the same as Experiment 3, except that participants completed more pairs of drives; were asked to rate their confidence in each judgment after making it; and completed the questionnaire on perceptual cues after the simulator session.

Participants

50 participants were recruited, different from those in Experiment 3, of whom 48 completed the experiment, and two withdrew. All participants were male and had a full UK driving licence. Potential participants who drove diesel vehicles were again excluded. The sample was intentionally recruited from relatively experienced drivers (mean number of years of driving experience 25.7 ± 9.9 ; mean annual mileage $17,244 \pm 10,616$ miles) to ensure that participants were able to attend to

the perception task rather than requiring cognitive resources for the driving control task. This had the effect that the sample had a somewhat high mean age (43.3 ± 9.4 years). However there is no evidence of significant age-related deterioration in visual, vestibular or cutaneous perception in the age range of the sample. Although hearing is known to deteriorate with age, the effects are small in the age range of the sample.

Results

Perception of acceleration difference

Initial Speed & Gear condition	VA _{max} condition	Mean (SD) time to complete (s)	Mean acceleration (ms ⁻²)	Mean difference in acceleration relative to VA0
ISG 1	VA9	2.54 (0.29)	3.34	4.37
	VA6	2.59 (0.31)	3.28	2.50
	VA3	2.60 (0.26)	3.27	2.19
	VA0	2.65 (0.29)	3.20	-
ISG 2	VA9	7.55 (0.25)	1.18	9.26
	VA6	7.82 (0.18)	1.14	5.56
	VA3	8.04 (0.22)	1.11	2.78
	VA0	8.31 (0.27)	1.08	-
ISG 3	VA9	10.68 (0.34)	0.84	10.53
	VA6	11.03 (0.35)	0.81	6.57
	VA3	11.39 (0.26)	0.78	2.63
	VA0	11.72 (0.57)	0.76	-

Table 6-3. Mean time to complete the acceleration, and mean acceleration rate, for each ISG and VA_{max} condition

Table 6-3 shows the mean acceleration rates achieved in each combination of initial speed and gear (ISG) and VA_{max} conditions. There were substantial differences in mean acceleration rate between the ISG conditions. Mean acceleration rates in the 1st gear, low initial speed condition (ISG 1) were in the range 3.20 – 3.34 ms⁻². In the 3rd gear, mid-range acceleration condition (ISG 2) they were

around three times lower, in the range 1.08 – 1.18 ms⁻², and in the high initial speed and gear condition (ISG 3) they were lower still, in the range 0.78 – 0.84 ms⁻².

Table 6-4 shows that the differences between actual acceleration rates achieved in the various VA_{max} conditions were close to the nominal differences of 3%, 6% and 9% in ISG 2 and ISG 3, but less in ISG 1. This indicates that in ISG 1, while higher acceleration was in principle available from the vehicle, it was not fully realised during the 2-20mph 1st gear acceleration. This may have arisen because participants’ response times from the “go” signal to fully depressing the accelerator control pedal (around 0.5 to 1 second) were relatively large compared with the overall time to complete the acceleration (around 2.6 seconds). This tended to make data this condition rather unreliable as a measure: perception of acceleration was partially confounded by participants’ response latencies²².

ISG	VA _{max} difference	Correct responses (%)	Incorrect responses (%)	X ² (1)	p
1	VA3 – VA0	51.5	48.5	0.09	0.765
	VA6 – VA0	54.3	45.7	0.64	0.424
	VA9 – VA0	61.6	38.4	5.76	0.016
2	VA3 – VA0	56.7	43.3	1.96	0.162
	VA6 – VA0	60.6	39.4	4.84	0.028
	VA9 – VA0	63.9	36.1	7.84	0.005
3	VA3 – VA0	52.5	47.5	0.25	0.619
	VA6 – VA0	59.8	40.2	4.00	0.046
	VA9 – VA0	57.6	42.4	2.56	0.110

Table 6-4. Perception of acceleration difference: X² tests. Bold type indicates conditions where difference met p < 0.05 criterion for statistical significance

²² Response latency here refers to the delay between the “Go” signal and achieving full pedal depression.

Figures 6-7 to 6-9 show the main results: the percentage of correct and incorrect responses for each vehicle acceleration difference pair, in each initial speed and gear condition. In ISG 1 and ISG 2, the difference between correct and incorrect responses increased as VA_{max} difference increased; so participants were better able to detect the difference correctly as the difference increased. This pattern was not repeated in ISG 3, where the observed difference between correct and incorrect responses was higher for VA6 than VA9. Across the set of vehicle acceleration difference conditions, the perceptual response (the difference between correct and incorrect responses) was higher in the ISG 2 condition than the other two ISG conditions.

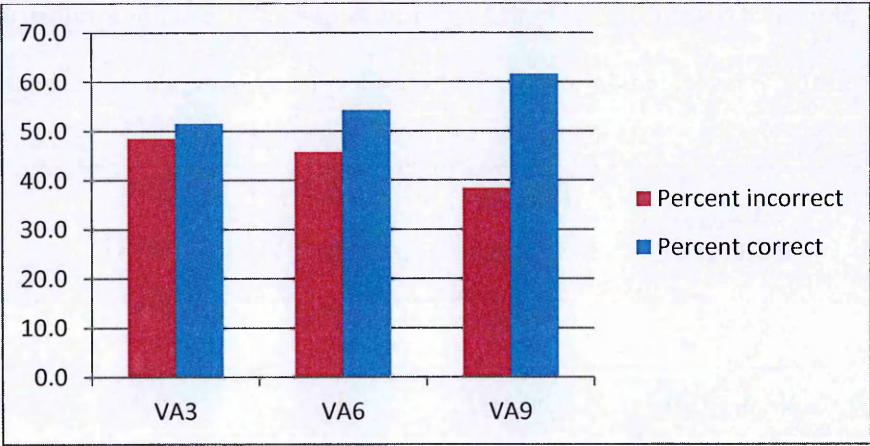


Figure 6-7. Perception of acceleration difference, ISG 1 (1st gear, 2 to 20 mph)

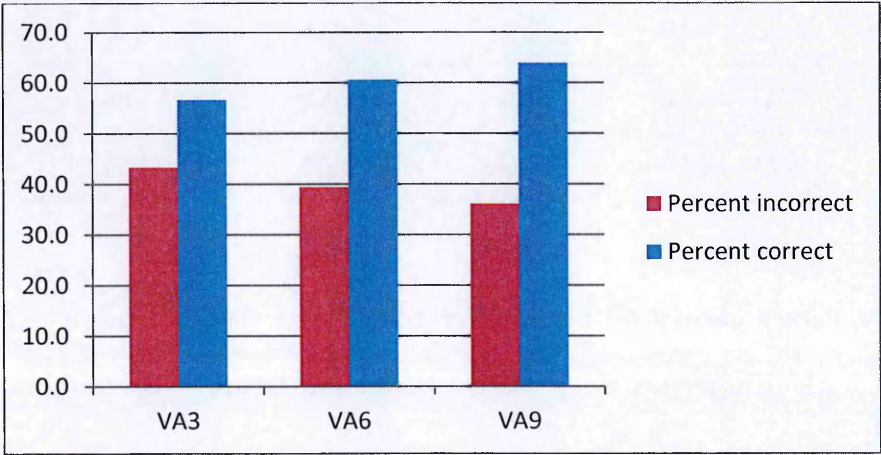


Figure 6-8. Perception of acceleration difference, ISG 2 (3rd gear, 30 to 50 mph)

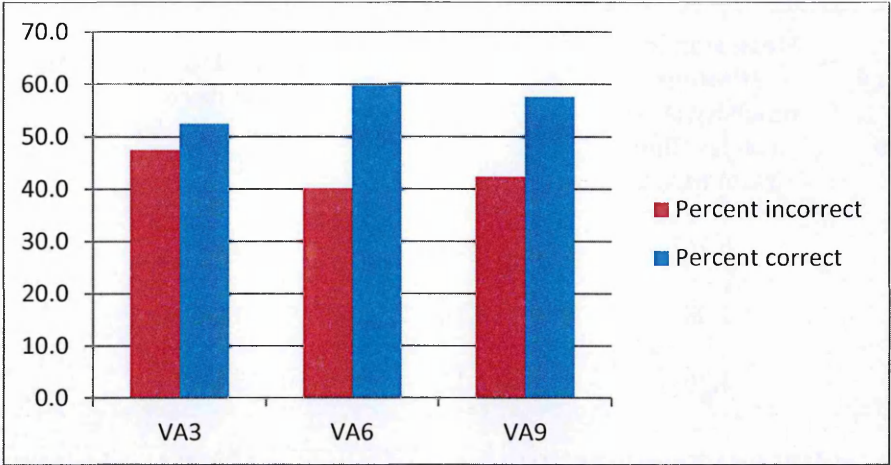


Figure 6-9. Perception of acceleration difference, ISG 3 (4th gear, 50 to 70 mph)

The bigger differences between correct and incorrect responses were statistically significant (using the conventional $p < 0.05$ criterion, χ^2 test), though the smaller ones were not (Table 6-4).

For each ISG condition, the ratios of correct to incorrect responses for each VA_{max} condition were fitted to a cumulative normal distribution using the Probit regression procedure with maximum likelihood estimation. Probit regression fits a model of the form:

$$PROBIT(p) = intercept + \beta x \quad \dots(6-8)$$

where the Probit function $PROBIT(p)$ is the inverse of the cumulative normal distribution. Table 6-5 shows the model parameters and χ^2 goodness-of-fit statistics. For all three models $p > 0.05$ so the hypothesis that the measured data differ significantly from the model distribution could be rejected.

Condition	Intercept	β	$\chi^2(2)$	p
ISG 3	0.011	0.026	0.606	0.739
ISG 2	0.022	0.039	0.112	0.946
ISG 1	-0.035	0.033	0.455	0.797

Table 6-5. Probit regression models for each ISG condition

Initial speed & gear condition	Mean standard stimulus intensity (VA0 acceleration rate) (ms ⁻²)	DL ₇₅ (ms ⁻²)	DL ₇₅ relative to standard stimulus VA0 (%)	DL _σ relative to standard stimulus VA0 (%)
ISG 3	0.76	0.20	27.2	40.3
ISG 2	1.08	0.16	14.6	21.6
ISG 1	3.20	1.12	34.9	51.8

Table 6-6. Difference Thresholds (DL) for acceleration in each ISG calculated from the Probit regression models

The difference thresholds (DLs) calculated from the models are shown in Table 6-6. DL_σ is the standard deviation of the cumulative normal distribution (i.e. the acceleration difference for which $z = 1$), and DL₇₅ is the difference threshold based on 75% correct response rate (i.e. the acceleration difference for which $z = 0.67$).

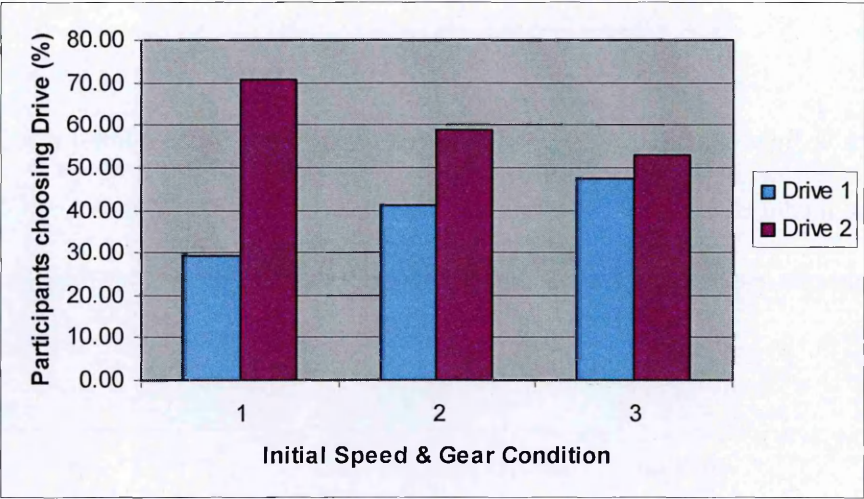


Figure 6-10. Order effect in VA0 – VA0 pairs

Figure 6-10 shows the percentage with which participants chose the first or second drive as fastest in the VA0-VA0 pairs, where in fact the same vehicle acceleration was available on both drives in the pair. There was a substantial order effect, such that participants tended to choose the second drive of the pair. The order effect was large in ISG 1, smaller in ISG 2 and negligible in ISG 3. The

order effect perhaps arose because of differences in the respective strengths of the memory traces for the first and second drives, since the first had to be retained in memory for longer than the second. The trend of decreasing order effect with ISG condition might be connected with the longer duration of acceleration experiences. The experimental design controlled for such order effects so the results were not expected to be affected.

Confidence in pair-wise judgments

Initial speed and gear condition	Vehicle acceleration condition pair	Confidence rating (SD)
ISG1	VA0 – VA0	6.37 (2.19)
	VA3 – VA0	6.47 (2.30)
	VA6 – VA0	6.74 (2.10)
	VA9 – VA0	6.50 (2.20)
ISG 2	VA0 – VA0	6.54 (2.23)
	VA3 – VA0	6.46 (2.26)
	VA6 – VA0	6.56 (2.05)
	VA9 – VA0	6.93 (1.99)
ISG 3	VA0 – VA0	6.63 (2.08)
	VA3 – VA0	6.70 (2.30)
	VA6 – VA0	6.97 (2.14)
	VA9 – VA0	6.84 (2.14)

10-point scale with two verbal anchors, 1 = no confidence and 10 = total confidence

Table 6-7. Means of participants’ ratings of their confidence in their pair-wise judgments, for each ISG and each VA pair

Table 6-7 shows the means of participants’ ratings of their confidence in their pair-wise judgments, for each initial speed and gear condition and each vehicle acceleration pair. All the ratings were similar, in the range 6.37 to 6.97, suggesting neither total confidence nor lack of it. ANOVA confirmed there were no significant main effects, interactions or differences between specific pairs

of conditions using the $p < 0.05$ criterion. Thus the observed increase in frequency of correct responses with increasing VA_{max} difference was not accompanied by any increase in confidence that the decision was correct. Nor was there any significance decrease in confidence in the $VA0 - VA0$ condition, when in fact there was no difference in the available vehicle acceleration.

Perceptual Cue	Mean rating (SD): how much cue influenced pair-wise decision
Time taken to reach the lead vehicle	4.76 (1.33)
Monitoring the speedometer	3.82 (1.41)
Changes in the pitch of engine noise	3.76 (1.35)
Changes in the loudness of engine noise	3.50 (1.30)
Physical sensation and feedback from the car	3.39 (1.41)
Monitoring the rev counter	3.14 (1.47)
Passing trees, signposts, etc.	3.04 (1.33)
Distance to the lead vehicle	2.96 (1.43)
Passing road markings	2.58 (1.44)

6 point scale with verbal anchors for each point (1 = None, 2 = Very little, 3 = Little, 4 = Moderate, 5 = Much, 6 = Very Much).

Table 6-8. Participants’ ratings of how much different perceptual cues influenced their pair-wise judgments about on which drive the acceleration was fastest

Table 6-8 shows the means of participants’ ratings of how much different perceptual cues influenced their pair-wise judgments about the drive in which the acceleration was fastest. The highest-scoring cue was *time taken to reach the lead vehicle*, followed by *monitoring the speedometer*. Both of these cues appear to involve an element of monitoring the time taken to reach a criterion event (passing the lead vehicle, reaching the target speed). Changes in the frequency (“pitch”) and loudness of the engine noise were the next highest rated cues.

Self-reports of cues used in pair-wise judgments

Participants were asked to indicate if they had used any other cues not included among the questionnaire items. Only one additional cue was reported. This was *counting during the acceleration*, mentioned by 9 of the 48 participants. For example:

Participant 32: *"I counted from the time the "go" came up to the time I passed the vehicle"*

Re-analysis with these 9 participants excluded produced no significant changes to the paired comparison results, so they were included in the final analysis.

Participants were also asked to indicate any differences in how they made the decision compared with how they expect they would have done it in a real car. Thematic analysis revealed two themes. The first was inertial forces, mentioned by 19 participants:

Participant 22: *"Yes. I didn't get a real feeling of acceleration where you are pushed back into your seat, so I felt a lot of the time I was guessing or not quite sure"*

The second theme was more influence from the frequency and/or loudness of engine noise, mentioned by 4 participants:

Participant 29: *"I wouldn't have counted in a real situation, but would be influenced by the engine noise/pitch"*

Discussion

Perception of acceleration differences

Weber's Law predicts that difference threshold should increase with stimulus intensity: in our case, with the magnitude of the acceleration experienced in each ISG condition. Table 6.2 shows that the acceleration rate was lowest for ISG 3 and highest for ISG 1; and the difference thresholds for these two conditions were approximately in proportion, as could be expected from a linear form of Weber's Law. However DL_{75} for mid-range accelerations (ISG 2) did not fit this pattern, being lower than either of the other values. Although I did not expect absolute validity in Experiment 4,

the difference threshold measured in ISG 2 was broadly similar to that found by MacNeilage et al. (2007) for a similar standard acceleration rate. This suggests the finding was not anomalous. The value of DL_{75} for mid-range accelerations in Experiment 4 was also broadly consistent with the values measured in Experiment 3 - lower than the value measured in the Visual, Auditory and Motion cue combination condition, but higher than that measured in the Visual cue only condition²³. It may be that the rather modest cue inconsistencies identified in Experiment 3 in ISG 2 were somewhat larger in the other two ISG conditions.

Confidence in pair-wise judgments

Participants were moderately confident in the accuracy of their judgments. However their level of confidence was independent of the actual VA_{max} difference in drive pairs – they were equally confident when there was in fact no difference, and there was no increase in confidence with VA_{max} difference to parallel the increase in correct judgments. It might be inferred that judgments were being largely made via non-conscious perceptual processes that did not contribute to conscious expression of confidence. Implicit perception leading to dissociations between self-reported confidence in judgments and perceptual awareness of the basis of those judgments, and/or judgment accuracy, has been discussed in the implicit learning literature (see, inter alia, Dienes, Scott, & Seth, 2010; Dienes & Seth, 2010; Overgaard, Timmermans, Sandberg, & Cleeremans, 2010).

Perceptual cues used, as reported by participants

Participants' self-reports suggested that the main cues that they were conscious of using to make their pair-wise judgments were *distance to the lead vehicle*, *engine loudness and frequency*, and *monitoring the speedometer*. Participants thus reported using cues from at least two sensory modalities, visual and auditory.

²³ Difference thresholds measured in Experiment 4, based on four data points per ISG condition, could be expected to be somewhat more reliable than those measured in Experiment 3, with two data points per cue combination condition

Two types of visual cue were provided in this experiment: optic flow cues (angular velocity of image texture elements, such as road markings and roadside features) and a lead vehicle moving at constant speed. *Distance to the lead vehicle* was rated as the most important cue. Much of the literature on perception in driving is concerned with the quantity “time-to-contact”, or tau, which represents a perceptual estimate of the time to reach an object ahead (Lee, 1976; Rock, Harris, & Yates, 2006). A quantity called “local tau” can be estimated entirely from the visual field, using information on the rate of growth of the angular size of the object in the field of view (Cavallo & Cohen, 2001). The importance of *distance to the lead vehicle* as a cue appears to relate to perception of tau. It also suggests that perception of acceleration in real driving may be very context-specific.

Although optic flow cues were not rated as important by participants, it is plausible that they were processed and used non-consciously.

Experiment 5: Absolute difference threshold for mid-range accelerations

Since Experiment 3 established that the driving simulator did not have absolute validity for perception of acceleration differences (because of inconsistencies between acceleration cues in different modalities, and the inadequacy of vestibular cues), a further experiment was carried out to measure the absolute difference threshold for mid-range accelerations, using the same experimental design but with a real car on a test track.

Method

Experimental design

Each participant completed 16 pairs of experimental drives, in which VA0 was paired four times with each of VA0, VA3, VA6 or VA9. The order of presentation was opposite for two of the four to control for order effects. The order of pairs was counterbalanced for each participant. The dependent variable was again frequency of correct pair-wise judgments.

Confidence in judgments, and self-reports of cues used

Participants were asked to report their level of confidence in their pair-wise judgments, in the same way as in Experiment 4. At the end of the experiment they completed a questionnaire in which they rated the importance in their judgments of a range of perceptual cues, again using a six point scale. The items in this questionnaire differed somewhat from those in Experiment 4, because of differences in the cues available in the real car/test track perceptual environment:

- Distance to visual reference point
- Time to reach a visual reference point
- Passing roadside objects
- Passing road markings
- Loudness of engine noise
- Pitch of engine noise
- Monitoring the Rev Counter
- Monitoring the Speedometer
- Feeling pushed into the seat
- Tilt of the vehicle

Test vehicle

The test vehicle was a 2007 Mk5 Golf TSi with a 1.4litre spark-ignition (gasoline) engine (Figure 6-11). In order to achieve acceleration levels approximately consistent with those in Studies 3 and 4, the engine output was reduced via the engine control unit (ECU) to 90bhp (from its standard 122bhp). The vehicle was fuelled with Shell V-Power (99 RON²⁴).

Different levels of VA_{max} were achieved using a controller provided by Revo Technik, connected to the car's On-Board Diagnostics (OBD) port, which communicated with the ECU to increase engine output as shown in Table 6-9.

²⁴ Research Octane Number

Data for velocity and position were recorded on each drive using a Racelogic VBOX Micro mounted inside the vehicle, equipped with GPS to locate the position of the vehicle to within $\pm 5\text{m}$, and recording data at a sampling frequency of 10Hz. Mean acceleration rates for the four engine output conditions are also shown in Table 6-9. The rate for condition VA3 was higher than expected, indicating that the controller did not function as intended in this condition. Nevertheless, using the mean acceleration rate, this condition still provided a useful data point.



Figure 6-11. Experiment 5 test vehicle (2007 Mk5 Golf 1.4 TSi, gasoline fuelled)

VA_{max} condition	Nominal engine output (bhp)	Actual mean acceleration (ms^{-2})	Standard deviation of actual acceleration (ms^{-2})
VA0	90.0	1.02	0.11
VA3	92.7	1.05	0.11
VA6	95.4	1.06	0.09
VA9	98.1	1.08	0.10

Table 6-9. Experiment 5: test vehicle engine output for each VA_{max} condition

Test track and route

The test route used the TRL Large Loop test track, driven in a clockwise direction (Figure 6-12). The Large Loop was 2.25km in length and similar in design to a single side of a motorway,

including gantries, crash barrier and signage. There were two main sections to each drive: the acceleration zone where participants accelerated the vehicle from 30mph to 55mph in 4th gear, and the question zone, where participants were required to choose the drive on which the car had accelerated the fastest. The acceleration zone was level and enclosed by trees which eliminated the possibility of trackside distractions. The preceding long curve gave ample time for participants to reach and maintain 30mph.

The acceleration zone consisted of four main sections (Figure 6-13):

1. 30mph zone, where participants were required to achieve a speed of 30mph and maintain 4th gear in preparation for the start of the acceleration event
2. Starting point for accelerations, indicated by a change in surface type, and by traffic cones.
3. Target speed zone, where most drives reached the target speed of 55mph.
4. Deceleration zone, where drivers began to slow down for the bend ahead

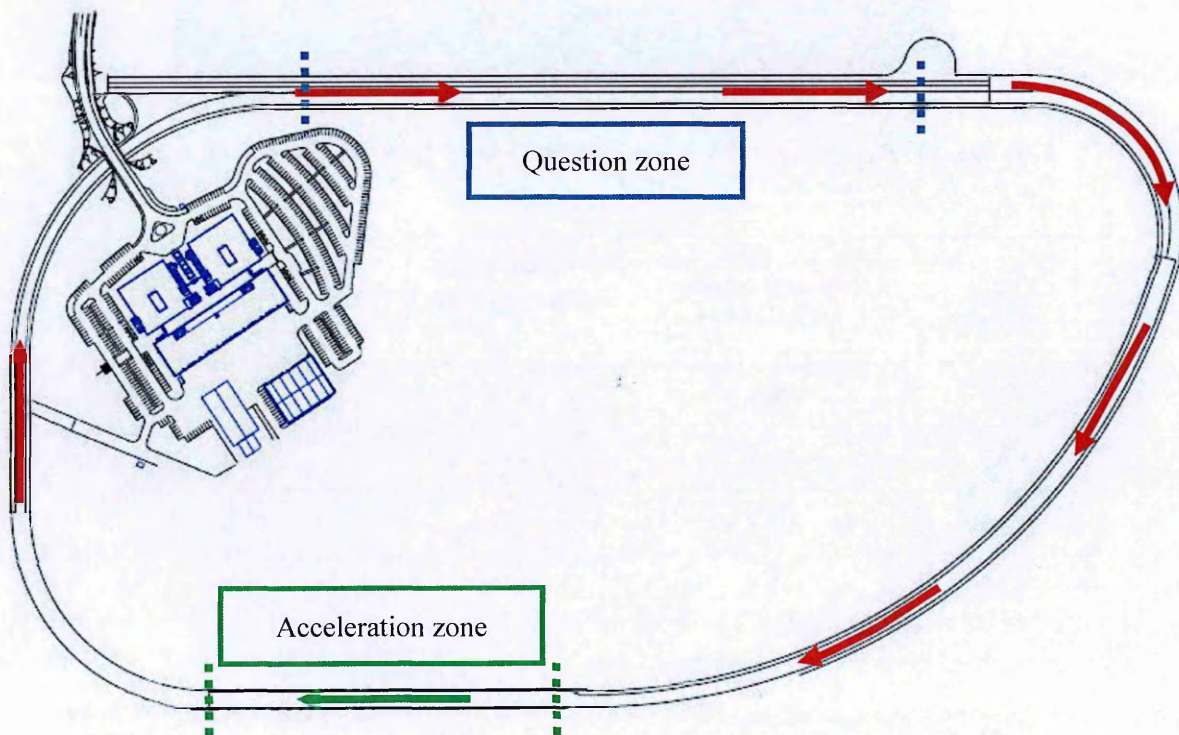


Figure 6-12. Test route

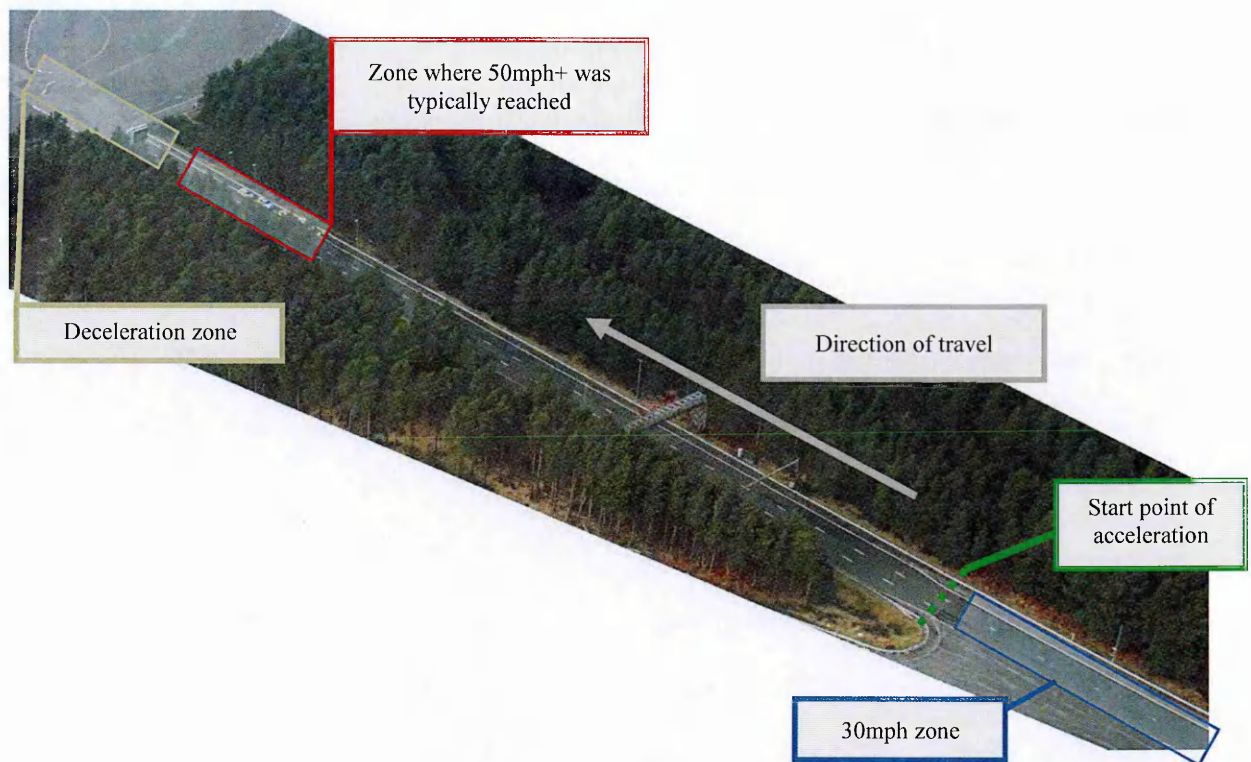


Figure 6-13. Acceleration zone

Procedure

Each participant was accompanied by a TRL researcher throughout the track session. The researcher initially drove the test vehicle to the question zone, where the participant was briefed, then drove to the acceleration zone and demonstrated how to complete the acceleration. Participants were briefed to depress the accelerator pedal fully when accelerating, and keep it fully depressed until the dashboard speedometer indicated they had exceeded 55mph (thus ensuring that the pedal remained fully depressed as the speed reached 50mph). The researcher and participant then exchanged places in the question zone and the participant began the first of two practice drives (further practice drives were made if a participant failed to complete the first two correctly).

On each experimental drive, participants attained and maintained a speed of 30mph in 4th gear in the 30mph zone. On reaching the starting point they fully depressed the accelerator pedal, keeping it fully depressed until the speed had exceeded 55mph, at which point they braked to decelerate. Participants then drove round the loop to the question zone. The researcher then adjusted the VA_{max} condition using the controller (out of sight of the participant), and, after each drive pair, asked the

participant to select on which drive the car had accelerated the fastest. For the first two drive pairs, participants stopped in the question zone, but for later pairs they were allowed to choose to give their responses while on the move (slowly) through the question zone, and all chose to do so. Completion of all 16 pairs took approximately 1.5 hours, and participants took a 10-minute break after 8 pairs.

On completion of all pairs, the participant and researcher again exchanged places, and the researcher drove the test vehicle off the test track.

Analysis

The ratios of correct to incorrect responses for each VA_{\max} condition (using the mean actual acceleration rates) were fitted to a cumulative normal distribution using the Probit regression procedure with maximum likelihood estimation.

Participants

49 participants completed the experiment (all different from those in Experiments 3 and 4). 24 participants were male, 25 female and had a full UK driving licence. Again the sample was intentionally recruited from relatively experienced drivers (mean number of years of driving experience 21.0 ± 13.2 ; mean age 40.3 ± 14.5 years) to ensure that participants were able to attend to the perception task rather than requiring cognitive resources for the driving control task.

Results

Perception of acceleration differences

Figure 6-14 shows the main results. The ratios of correct to incorrect responses were clearly larger than those measured in Studies 3 and 4 for the equivalent speed range in the driving simulator (Figures 6.6 and 6.8), and all were statistically significant.

Table 6-10 summarises the Probit regression model fitted to the data, and the difference thresholds calculated from the model.

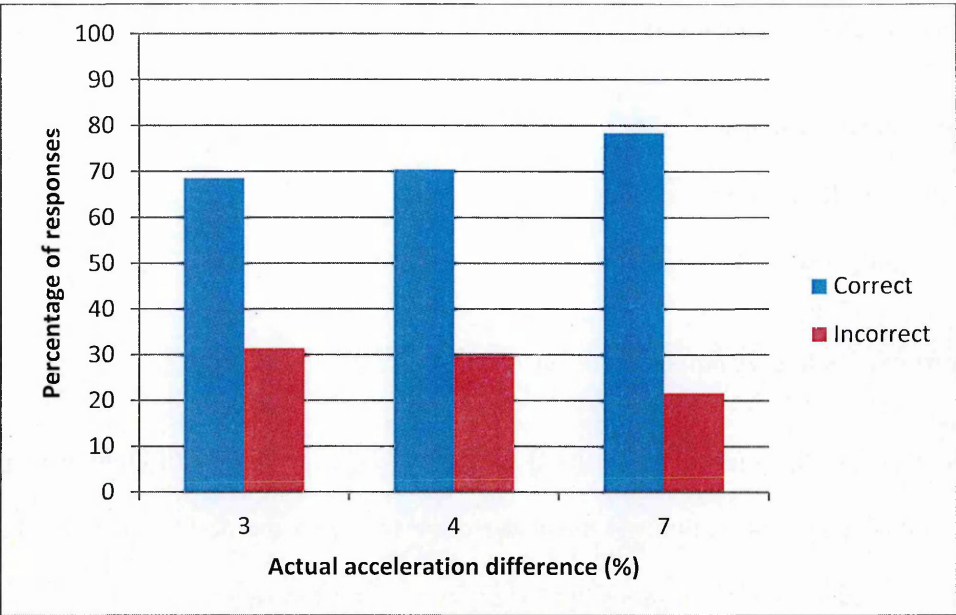


Figure 6-14. Experiment 5: Perception of acceleration difference, 4th gear, 30 to 50 mph, 2007
Mk5 Golf 1.4 TSi, gasoline fuelled, test track

Condition	Intercept	β	$\chi^2(2)$	p	DL ₇₅ (ms ⁻²)	DL ₇₅ relative to standard stimulus VA0 (%)	DL _{σ} relative to standard stimulus VA0 (%)
30-50mph acceleration	0.011	0.026	0.606	0.739	0.08	7.66	11.34

Table 6-10. Experiment 5: Regression model and difference thresholds, 30mph – 50 mph
acceleration

Vehicle acceleration condition pair	Confidence rating (SD)
VA0 – VA0	6.19 (2.25)
VA3-VA0	6.45 (2.14)
VA6-VA0	6.34 (2.14)
VA9-VA0	6.46 (2.06)

Table 6-11. Experiment 5: Participants’ ratings of confidence in their pair-wise judgments

Confidence in pair-wise judgments

Table 6-11 shows participants’ mean ratings of confidence in their pair-wise judgments for each VA_{max} condition. Ratings were similar to those for the equivalent speed range in Experiment 4 (if anything, slightly lower). The small differences between VA_{max} conditions were not significant.

Self-reports of cues used in pair-wise judgments

Table 6-12 shows the means of participants’ ratings of how much different perceptual cues influenced their pair-wise judgments about the drive in which the acceleration was fastest. The most highly rated cues were *distance* and *time to a visual reference point*, and *monitoring the speedometer*. Neither *loudness* nor *pitch of the engine noise*, nor *feeling pushed into the seat*, was rated particularly highly.

Perceptual Cue	Mean rating (SD): how much cue influenced pair-wise decision
Distance to visual reference point	3.57 (1.27)
Time to reach a visual reference point	3.18 (1.35)
Passing roadside objects	2.24 (1.44)
Passing road markings	1.75 (1.23)
Pitch of engine noise	2.06 (1.28)
Loudness of engine noise	1.96 (1.28)
Monitoring the Rev Counter	1.45 (1.46)
Monitoring the Speedometer	3.47 (1.30)
Feeling pushed into the seat	2.08 (1.40)
Tilt of the vehicle	1.02 (1.03)

6 point scale with verbal anchors for each point (1 = None, 2 = Very little, 3 = Little, 4 = Moderate, 5 = Much, 6 = Very Much).

Table 6-12. Participants’ ratings of how far different perceptual cues influenced their pair-wise judgments about on which drive the acceleration was fastest

Discussion

Perception of acceleration differences

The most striking aspect of Experiment 5 is that the difference threshold measured for mid-range accelerations (0.08 ms^{-2}) was around half the values measured in the driving simulator, thus confirming my earlier conclusion that the driving simulator did not have absolute validity for perception of acceleration. This value was also around half the values measured by MacNeilage et al. (2007), supporting the suspicion I expressed in Chapter Four that difference thresholds in actual driving might be lower because of the much richer mix of cues available. As I noted in Chapter Four, the difference in manufacturers' claimed 0-60mph acceleration times between engine size increments tends to be in the region of 12-15% (e.g. between 1.4litre and 1.6litre engine versions of the same model). It seems reasonable to expect that manufacturers have learned to establish engine size increments that provide acceleration benefits exceeding the difference threshold. 12-15% differences just exceed my measured value for DL_{50} , meaning that drivers would be able to perceive them on most occasions, at least in a careful paired comparison, if not necessarily in naturalistic driving.

Confidence in pair-wise judgments

Confidence ratings again did not increase significantly with increasing VA_{\max} difference, even though the frequency of correct responses was higher than in Experiment 4. This supports the inference drawn from Experiment 4 that judgments were being made via non-conscious perceptual processes.

Perceptual cues used, as reported by participants

Among the most important cues that participants reported using were *distance* and *time to a visual reference point*. These cues bear some similarity to the time to lead vehicle cue in Experiment 4 (although visual reference points available to Experiment 5 participants were all stationary, rather than moving as was the lead car in Experiment 4). Perhaps rather surprisingly, neither of the auditory cues, (loudness or pitch of engine sound) was rated highly. Neither was the feeling of

being pushed back into the seat, a cue that was missing from the driving simulator studies. Yet the frequency of correct judgments was significantly higher in Experiment 5 than in Experiments 3 and 4. This again suggests that participants were not consciously aware of the cues that were influencing their judgments.

General Discussion

In Table 6-13, the results of Studies 4 and 5 are combined, to give the measured absolute difference threshold for 30-50mph acceleration, and estimated absolute difference thresholds for 0-20mph and 50-70mph accelerations. This provides a complete picture of the acceleration differences a vehicle designer seeking to establish an acceleration performance benefit needs to achieve.

Study 1 found that drivers’ construals of dynamic performance included both acceleration from standing start (speed range 0-20mph in Table 6-13) and mid-range acceleration (speed range 30-50mph) particularly when overtaking. Because of the higher acceleration rates involved, the difference threshold for accelerations from standing start is much higher than that for mid-range accelerations. For the designer of an EV this is a happy coincidence, as electric motors have a particular advantage of high torque at low speeds.

Speed range (mph)	Typical acceleration rate* (ms ⁻²)	DL ₇₅ (ms ⁻²)	DL _σ (ms ⁻²)	DL ₇₅ (%)**	DL _σ (%)**
0-20***	3.2	0.56	0.84	17.5	25.7
30-50	1.08	0.08	0.12	7.7	11.3
50-70***	0.76	0.10	0.15	13.2	19.4

* Typical acceleration rate for a C segment family hatchback, 1.4litre spark ignition (gasoline) engine

** Relative to the typical acceleration rate

***Estimated

Table 6-13. Difference thresholds for acceleration when driving, in three speed ranges

The three studies confirm that perception of acceleration in driving involves the combination of multiple cues from different sensory modalities. This has an important consequence, since it means that perception of acceleration must be context-dependent. Finer perceptual discriminations may be possible in a driving environment that is richer in visual cues. Further driving simulation experiments could be used to investigate these effects.

Acceleration benefits of the size shown in Table 6-13 would be sufficient to enable an EV to be perceived as having better dynamic performance than a conventional ICE car of the same size, in a direct back-to-back comparison. Drivers rarely experience the opportunity to make such direct back-to-back comparisons, however. Perhaps the closest analogy in everyday driving experience is test driving a potential new car when considering a purchase, but in this situation there may be a substantial interval, at least minutes long, between driving one's own and the test vehicle; and the traffic situation might in any case make opportunities to accelerate somewhat different. This suggests that in practice, acceleration differences might need to be bigger than the difference thresholds.

Although earlier generations of EVs have been perceived by consumer drivers as under-powered (Graham-Rowe et al., 2012), it is certainly feasible for designers to achieve such dynamic performance benefits (see Chapter Eleven), and indeed, potentially offer even higher performance. However rapid accelerations deplete the battery of an EV. In a BEV, where battery capacity and short range between recharges is a significant issue, the designer should offer just enough acceleration benefit to interest potential users, but not so much as to substantially reduce the range. This suggests that acceleration benefits should be kept to the minimum needed to convey a tangible benefit: somewhat higher than the difference thresholds in Table 6-13, but not so high as to waste too much valuable battery capacity. In a PHEV or E-REV, however, battery capacity is of less concern, and dynamic performance in a PHEV can be achieved by combining the outputs of the electric and ICE powertrains, so it may be that higher performance can be achieved with these types without having to make the same trade-off.

The three studies also lend support to the hypothesis that, at least close to the difference threshold, perception of acceleration differences must have a substantial contribution from non-conscious,

implicit processes. I shall explore this in more depth in Experiment 6 in the next chapter, and suggest that in fact, differences smaller than the perceptual difference thresholds might still affect drivers' comparative responses to different vehicles, through a process of implicit learning.

Chapter Seven. Explicit and implicit learning of vehicle performance

In Study 1 (Chapter Three), the themes *Confidence in ability to overtake* and *Confidence in Safety* in drivers' construals of vehicle performance did not relate to the direct experience of performance, but rather to drivers' "confidence" in being able to perform manoeuvres such as overtaking that require it. I suggested that, in experiencing different levels of confidence, drivers must access a mental model of the performance of their vehicle, and evaluate whether that performance was sufficient to enable the manoeuvre to be carried out successfully (with some margin of safety).

The mental model that the driver accesses must represent the set of relationships between the physical acceleration that will be attained, and VA , initial speed and load, gear selection and accelerator pedal depression, contained in equation 4-14:

$$A = f(VA, \text{speed}, \text{load}, \text{gear}, PD) \quad \dots(4-14, \text{repeated})$$

These relationships must be learnt from prior direct perceptions of vehicle performance. In the model developed in Chapter 4, the mental model reflected in equation 4-14 provides the Bayesian prior in direct perception of acceleration. However in this Chapter I am concerned with access to the model in anticipation of, rather than during, actual accelerations.

It is not necessarily the case that a driver is aware of the knowledge encoded in the mental model represented by equation 4-14. The knowledge used to control a behaviour is said to be *implicit* when there is dissociation between that knowledge and a person's ability to report how the behaviour is controlled. Procedural knowledge, such as how to ride a bicycle, is often considered to be implicit in this sense. Catching a ball is a well studied example (Chapman, 1968; Chodos, Lifson, & Tabin, 1995; Dienes & McLeod, 1993; McLeod & Dienes, 1996; McLeod, Reed, & Dienes, 2001). Reed et al. (2010) found that people are unable to describe how they decide whether to move backwards or forwards to catch a ball, and even when prompted with the appropriate perceptual cue, they are unable to describe how they use it.

Ball catching is a skill that is often learnt years before a particular instance of the behaviour (a catch), so that control of the behaviour depends on access to stored knowledge acquired in the past. There are some limited parallels between this and accessing a mental model of vehicle performance, particularly when driving one's own car: we can assume that the driver has acquired the mental model in the past, through previous experience of using the car. Although evaluation of overtaking opportunities requires specific information about available rates of acceleration, there was nothing in Study 1, which elicited drivers' consciously accessible constructs of performance, to suggest that this specific information was consciously accessible. This suggests that the mental model is in the form of implicit knowledge of exactly how the vehicle will perform.

Much of the research literature focuses on the processes by which implicit knowledge is acquired, rather than its retention and retrieval. The term *implicit learning* is used to characterise the processes that take place when a person learns about (acquires knowledge of) the structure of a complex stimulus environment, without necessarily intending to do so, and in such a way that the person is unable to report the knowledge explicitly (Berry, 1997).

Implicit learning has been studied in a variety of contexts and experimental paradigms. One of the most frequently studied is artificial grammar learning (Dienes, Broadbent, & Berry, 1991; Matthews, Buss, Stanley, Blanchard-Fields, Cho, & Druhan, 1989; Miller, 1969; Reber, 1967, 1976, 1993). In a typical artificial grammar learning experiment, participants study sets of exemplars, for instance of strings of letters (which they are initially led to assume are randomly generated), expecting a memory test on these items. Later, they are told that the strings were in fact generated by a complex set of rules (the "artificial grammar") and asked to judge whether new strings comply with the rules or not. Typically, participants judge correctly at above chance levels, and approximately as well as other participants who were explicitly told about the grammar and instructed to try to work out its rules during the initial task. It appears that they learnt the rules of the grammar implicitly, without awareness that they were doing so, through exposure to grammatically correct strings in the initial task.

A second context that is more relevant to driving is that of the control of complex systems (Berry & Broadbent, 1984, 1988; Broadbent, 1977; Broadbent & Aston, 1978; Dienes & Fahey, 1995, 1998;

Geddes & Stevenson, 1997; ni Dhiomasaigh & McCarthy, 1995; Stanley, Matthews, Buss & Kotler-Cope, 1989). Broadbent (1977) and Broadbent, FitzGerald and Broadbent (1986) tested participants' ability to control a model of a city transportation system, finding that they produced a higher frequency of correct decisions after practice than without practice, though they were unable to report having any knowledge of relationships within the system, acquired during practice, that had informed their decisions. Similarly Broadbent and Aston (1978) and Broadbent, FitzGerald, & Broadbent (1986) found that teams of managers making decisions in relation to a model of an economy produced a higher frequency of correct decisions after practice involving feedback on accuracy, but did not improve their performance on a set of questions about the principles underlying the model. In such cases it appears that participants learn the rules of the complex system implicitly, without awareness that they are doing so, through practice and feedback. Broadbent et al. (1986) proposed that implicit learning of the control of complex systems could be understood in terms of episodic memory for specific events related to the control task. They suggested that participants constructed a "look-up table" that would determine the appropriate behaviour by matching of the current situation to the most similar of the entries currently in the table. Dienes & Fahey (1995, 1998) found evidence to support this using two control systems: first, process control of a simulated sugar factory, and second, a person interaction task in which participants manipulated the friendship shown by a computer personality by their responses to it.

There are parallels between the task of evaluating overtaking opportunities and the control of complex systems paradigm. Each instance of overtaking (or indeed of accelerating) in different circumstances might add a new entry to the look-up table so that with experience it might form a rich, finely incremented database whose outputs might approximate closely to using a predictive equation with continuous variables.

In this model of implicit learning, encountering a novel situation should cause new entries to be added to the look-up table. In driving, this might be the case when driving an unfamiliar car: whilst the way its performance varies with initial speed, load, gear selection, etc. might be broadly similar to that presently encoded in the table, it would differ in detail. The original table might therefore be modified to encode an additional variable, "vehicle", to account for which vehicle the driver was

using; or a new table might be formed for each vehicle, with entries for any new vehicle perhaps initially filled by copying from the original.

In Experiment 2 I found that there was no significant difference between participants' ratings of perceived acceleration between the low and high acceleration conditions in the DigiCar simulator (representing a difference in VA of 8% over the 30-50mph speed range); and Experiment 4 found that the difference threshold DL_{75} for conscious report of acceleration differences in the 30-50mph speed range was 14.6%. Taken together, these suggest that acceleration differences of around 8% in the simulator will not generally be consciously reportable. However the argument above suggests that it is plausible that subtle differences in vehicle performance could be learnt implicitly through experience, and thereby affect a driver's evaluation of overtaking opportunities, giving rise to different experiences of "confidence" in ability to overtake successfully, and differences in actual overtaking behaviour, without the driver being consciously aware of the performance difference.

Experiment 2 found evidence of differences in driving behaviour as a result of the 8% difference in VA, but those could be attributed to direct perception of the vehicle's motion affecting the in-the-moment operation of a goal-pursuit feedback loop, without any intervening access to a mental model of the vehicles' performance. To investigate whether implicit learning of small acceleration differences can update the mental model and cause changes in driving behaviour, a paradigm is needed in which a driving behaviour depends specifically on accessing the contents of the mental model, and that access is disambiguated from immediate feedback. As discussed above, decisions to overtake provide this opportunity, since at the moment of decision, the mental model has been accessed but the present acceleration rate is still zero, so there has been no direct perception of acceleration.

Experiment 6 was therefore designed to investigate whether experiencing small differences in levels of performance from a vehicle, in naturalistic driving, led to differences in subsequent overtaking decisions. The performance difference studied (8%) was smaller than the DL_{75}

perceptual difference threshold measured in Experiment 4, so that drivers would not be able to verbally report it²⁵. It was assumed that in this case, differences in overtaking decisions between the two performance conditions must result from a process of implicit learning of the vehicle's performance.

For comparison, the experiment also investigated whether explicit learning about the vehicle's performance (being directly told as part of the experiment briefing) led to differences in subsequent overtaking decisions.

Experiment 6 was carried out in a driving simulator. The literature on implicit learning in the control of complex systems has largely been based on laboratory experiments, using model systems implemented on computers. This has the merit of high internal validity, but carries the risk of low external validity: it has not been convincingly demonstrated that implicit learning effects that can be found in controlled laboratory conditions generalise to the much more complex real world. Investigating implicit learning using a driving simulator therefore extends the implicit learning literature, because a simulator provides a rich, immersive virtual reality, with higher external validity than a laboratory experiment, but without loss of the high internal validity of a laboratory experiment. It thus provides the opportunity to observe implicit learning in a context much closer to everyday life than a typical laboratory experiment.

Method

Simulated overtaking situation

Experiment 6 was carried out in the TRL DigiCar simulator described in Chapter Five. The experimental route consisted of six different zones, each serving a different purpose:

²⁵ Note that the DL_{75} in a real vehicle, as shown in Experiment 5, is smaller than this value, because more perceptual cues are available; thus had this experiment been carried out in a real vehicle, a smaller acceleration difference would have been needed to ensure that participants could not verbally report it.

Zone 1: A 3-4 km warm up section to allow participants to familiarize themselves with the simulator and the handling properties of the vehicle.

Zone 2: A vehicle experience section, in which participants encountered a number of road features that required them to slow down and then accelerate back up to speed. This allowed participants to experience the acceleration performance of the vehicle prior to the overtaking event. It included four specific road features: (1) a right turn across an oncoming stream of traffic; (2) an artificial road narrowing feature (a narrow bridge, with stone walls to either side); (3) a left followed by a right hand bend, each sharp enough to require the participant to slow down; and (4) a small village through which the speed limit was 30 mph. Driving behaviour was recorded during this section as part of an additional study into the validity of the Multi-Dimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari, Mikulincer, & Gillath, 2004) which is not reported here.

Zone 3: A practice overtaking section. On entering this zone on a two-lane, bi-directional single carriageway, participants encountered a train of vehicles travelling at 30 mph (where the road speed limit was 60 mph). Initially a steady stream of oncoming vehicles prevented overtaking, forcing participants to follow behind at 30 mph. An additional lane then opened, offering an opportunity to overtake. The whole of the three-lane section made a gentle right hand bend, enabling the participant to see the lead vehicle in the train (a lorry, therefore visible in any case over the tops of the intervening vehicles) and the length of the train (Figure 7-1). The end of the three-lane section was marked by an overhead sign gantry indicating lane closure, visible from the start. Participants could therefore see both the length of the vehicle train to be overtaken, and the distance available for overtaking, at the point where the overtaking opportunity began.

This zone was intended to provide participants with an opportunity to practice judging available distance and overtaking opportunity. The three-lane section was repeated five times within Zone 3, with five progressively longer vehicle trains (of four, five, six, seven and then eight vehicles). If the participant did not overtake on any three-lane section, the vehicle train exited the road down a slip road on the left hand side immediately after the three-lane section. Before each new three-lane section a further train pulled onto the road ahead, presenting a fresh overtaking challenge.



Figure 7-1. Overtaking section, with a train of four vehicles to be overtaken. The sign gantry visible in the distance marked the end of the overtaking opportunity

Zone 4: A further vehicle experience section, identical to zone 2.

Zone 5: An overtaking test section, similar in layout to Zone 3. Just before each of the five three-lane sections, participants encountered a vehicle train to be overtaken. To vary the overtaking difficulty, the length of the vehicle train was four, five, six, seven or eight vehicles, and the order of presentation of train lengths was randomized between participants.

Zone 6: A final vehicle experience section, used in the additional MDSI study.

Each experimental drive took approximately 30 minutes. Participants completed four experimental drives each (see next section), so their total time in the simulator was around two hours, around the maximum above which fatigue might affect experimental performance.

Experimental design

As Experiment 2 showed, there can be substantial individual differences between participants' driving behaviours. To control for this, Experiment 6 used a within-participants design. There were three independent variables: vehicle performance, explicit information, and overtaking difficulty.

The dependent variable was the overtaking decision made at each overtaking opportunity. Each participant completed four experimental drives, one in each combination of the levels of vehicle performance and explicit information. The order of drives was randomised between participants. The different levels of overtaking difficulty were each experienced within each drive, and again the order of presentation was randomised between participants.

Vehicle performance

There were two levels of vehicle performance, the same as those used in Experiment 2: *standard vehicle acceleration* - the standard performance of the vehicle dynamics model, representing a typical C segment medium family hatchback car; and *higher vehicle acceleration* – in which the simulated vehicle's acceleration in the relevant speed range was 8% higher than standard. This difference was substantially lower than the DL₇₅ difference threshold of 14.6% measured in the ISG2 30-50mph speed range in Experiment 4. It was therefore assumed that the difference in acceleration between the vehicle performance conditions could not be verbally reported by participants (as was the case for a difference of this size in Experiment 2).

Explicit information

Prior to each drive, participants were given either of two briefings concerning the performance of the simulated vehicle: that the simulated vehicle was set up to have similar performance to a standard car of its size (*standard performance information condition*), or that the simulated vehicle was set up to have higher performance than a standard car of its size (*higher performance information condition*). Specifically, the instructions were:

“For the trial today you will be driving through a rural route. Please attempt to complete the route as if late for an important meeting. On a number of occasions along the test route, you will encounter slow moving traffic being held up by an HGV. If you feel it is safe to do so, you should attempt to overtake the queue of traffic. Only attempt to overtake the queue of traffic if you feel you can overtake the lorry at the head of the queue. The drive will last approximately 30 minutes.”

And:

[Standard performance information condition] “*For this drive the simulator has been set up so that you will be driving a car that has average acceleration for this type of car*”.

Or:

[Higher performance information condition] “*For this drive the simulator has been set up so that you will be driving a car that has eight per cent higher acceleration than average for a car of this type*”.

Overtaking difficulty

In Zone 5, participants encountered vehicle trains of varying lengths (four, five, six, seven and eight vehicles). The eight-vehicle train represented a very high level of overtaking difficulty – it could only be overtaken successfully within the length of the three-lane section if a driver made an immediate decision to overtake and immediately applied maximum accelerator pedal depression until the train was passed). This was intended to be a condition too difficult for participants to attempt, and most did not; on the few occasions when attempts were made, they were aborted before the end of the three-lane section, or participants over-ran the section in the opposite lane, crossing the double white lane separator lines (which is not permitted in UK driving). The seven-vehicle train therefore represented the most difficult, but credible, overtaking opportunity. In the analysis that follows results are compared between the *least difficult* condition (four-vehicle train) and this *most difficult* condition (seven-vehicle train)²⁶.

²⁶Overtaking decision data for the other vehicle train lengths was used to calculate an overall frequency of positive decisions to overtake in a supplementary study of individual differences, which is reported in Appendix 1.

Dependent variable

The dependent variable was overtaking decision, with two values, *positive decision* and *negative decision*. The decision was classed as positive if the participant crossed the lane boundary into the overtaking lane *and* depressed the accelerator pedal. If these conditions were not both met, the decision was classed as negative. Positive decisions were classed as such whatever their outcome (some participants, having decided to overtake and begun the manoeuvre, subsequently changed their minds and attempted to pull back into the left lane, either behind the vehicle train or into it).

Implicit learning experiments typically include a dependent measure of awareness, usually a verbal self-report. In Experiment 6 I did not record self-reported ratings of available vehicle performance, because in a within-participants design this could have drawn participants' attention to vehicle performance, with a risk of affecting the learning processes in subsequent drives. This aspect of the method is further discussed in the sub-section on methodology in the Discussion section later in this Chapter.

Participants

There were 48 participants, 24 male, 24 female, with a mean age of 35.8 ± 9.8 years. All were regular drivers, with a mean annual mileage of 14635 ± 10713 . Mean number of years of driving experience was 15.3 ± 10.0 years.

Results

Of the 48 participants, two failed to complete all four drives (because of crashes); eleven made no positive decisions to overtake and a further three made only one or two positive decisions. These were excluded from this analysis, leaving 33 participants from whom valid data was collected.

There were significant main effects of overtaking difficulty ($F(1,33) = 45.15$, $p < 0.001$) and vehicle acceleration ($F(1,33) = 4.313$, $p = 0.046$) on the frequency of positive decisions to overtake, and a near-significant main effect of explicit information ($F(1,33) = 3.873$, $p = 0.058$). There were no significant interactions.

Figures 7-2 and 7-3 show the results for the *least difficult* and *most difficult* overtaking difficulty conditions respectively. There was a substantial difference in frequency of positive decisions to overtake between the two overtaking difficulty conditions, with more than twice as many positive decisions in the least difficult condition compared with the most difficult.

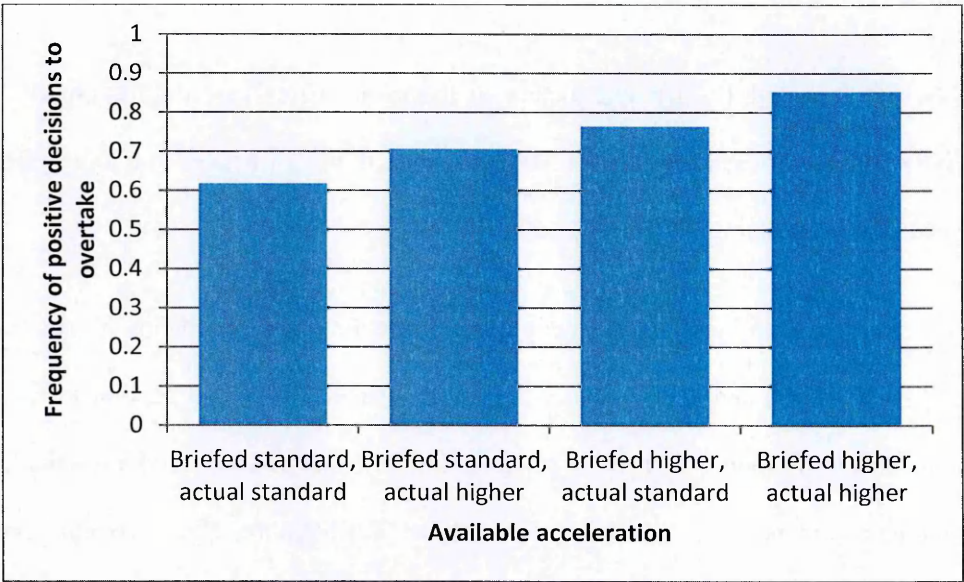


Figure 7-2. Frequency of positive decisions to overtake versus explicit information and vehicle acceleration conditions (*least difficult* overtaking condition, four-vehicle train)

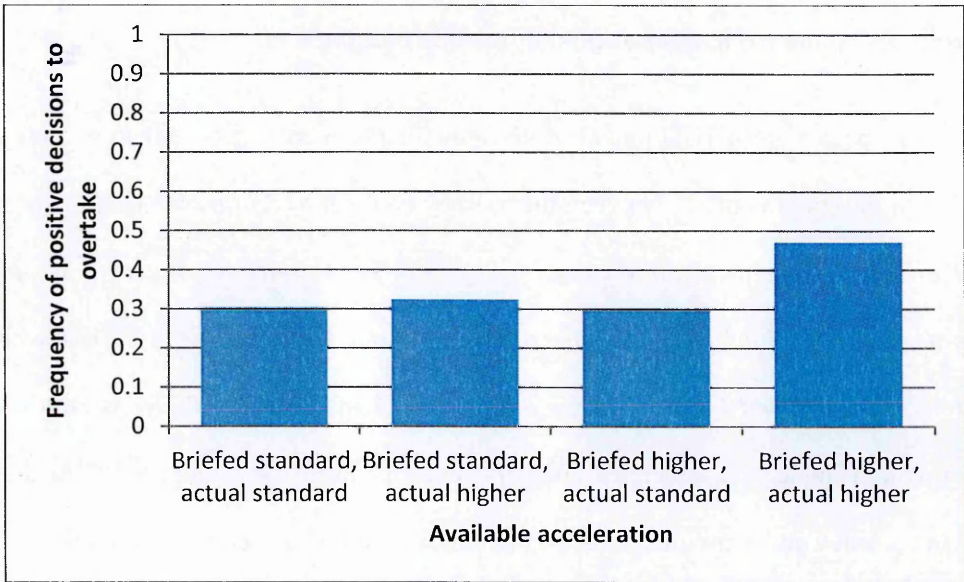


Figure 7-3. Frequency of positive decisions to overtake versus explicit information and vehicle acceleration conditions (*most difficult* overtaking condition, seven-vehicle train)

Figure 7-2 shows that in the *least difficult* condition, both explicit information that the vehicle's performance was higher than standard, and experience of higher performance, led to a greater frequency of positive decisions, and a still greater frequency was found when participants received both explicit information that the vehicle's performance was higher, and experience of higher performance.

Figure 7-3 shows a slightly different picture in the most difficult overtaking condition: neither explicit information nor experience of higher performance on its own led to a higher frequency of positive decisions, but their co-occurrence did.

To summarise, the results show that both explicit information that a vehicle has higher performance (whether it does or not) and experience of higher performance (whether accompanied by explicit information that performance is higher, or not) lead to changes in overtaking behaviour, i.e. a higher frequency of positive decisions to overtake. Furthermore, these effects appear to be independent, and additive.

Discussion

Overtaking decisions from an inter-goal dynamics perspective

From the perspective of the IGD model of driving (Chapter Four), decisions to overtake represent the resolution of a goal conflict, between the journey goal *get to destination as quickly as possible* and *symbolic goals such as signal my masculinity to others through driving style* or *conform with dynamic driving behaviour of my social group* on the one hand, and safety goals such as *avoid harm to myself* and *avoid harm to others* on the other hand. When a driver is held up behind a slower-moving vehicle, discrepancies gradually accumulate at the comparators in the feedback loops of the journey and symbolic goals, so their activation levels increase, motivating the driver to overtake to reduce those discrepancies.

However if the situation is perceived as unsafe for overtaking (because of collision risk) then the activation levels of the safety goals also increase²⁷. The extent to which this happens depends on an evaluation of the feasibility of accelerating, passing the leading vehicle and returning to the appropriate lane (and slowing to the appropriate speed, if required), all before reaching any road features or oncoming traffic ahead with which a collision might occur. To carry out this evaluation, the driver must access a mental model of the acceleration performance of the vehicle being driven.

Updating the mental model: explicit and implicit learning

The performance of vehicles is not constant but varies with factors such as load, ambient air temperature, fuel, maintenance state, state of tyres, etc. Thus to be accurate, the mental model must adapt to such changes: it must be capable of being updated. Experiment 6 investigated two processes by which this might occur: explicit learning from information available directly, and implicit learning from experience of the vehicle's performance.

The experiment showed, first, that drivers' decisions to overtake are affected by explicit information about the performance of their vehicle: they are, to some extent, more likely to decide to overtake if told that their vehicle has higher performance than a standard car, even if in fact it does not. This suggests that explicit learning about a vehicle's performance can directly lead to updating of a driver's mental model of its performance.

Second, the findings suggest that experiencing differences in the actual performance of a vehicle can also lead to differences in overtaking behaviour, even if the differences in performance are below the perceptual difference threshold and thus unavailable to verbal report. This suggests that changes in the vehicle's performance can be learnt implicitly, through experience, leading to

²⁷ Before starting to overtake, of course, the safety goals are already being met, through the following behaviour, so their activation levels should be low. For the activation level of a safety goal to increase in the absence of an immediate perceived threat, the perceived state of the world must include *internal* information about the activation states of other goals. Therefore increased activation of a goal, the fulfilment of which entails a risk, causes increased activation of safety goals in anticipation of that risk.

changes in the driver's mental model, without the driver being consciously aware that this is happening²⁸.

In the first section of this chapter I discussed the model proposed by Broadbent et al. (1986), subsequently supported experimentally by Dienes & Fahey (1995, 1998), that implicit learning of the control of complex systems could be understood in terms of a "look-up table" of episodic memories for specific events related to the control task, that would determine the appropriate behaviour by matching of the current situation to the most similar of the entries in the table. There has been considerable debate in the literature over whether implicit learning is best understood in terms of such instance-based or episodic accounts (Neal & Hesketh, 1997), or in terms of the unconscious abstraction of general rules (Matthews & Roussel, 1997; Reber, 1976, 1989). Most of this debate has centred on artificial grammar learning, the experimental paradigm that has been used most frequently in implicit learning research. Models based on abstraction of general rules are perhaps more widely accepted in relation to artificial grammar learning (Berry, 1997). It is not yet possible, therefore, to propose a definitive account of the mechanism of that may underlie the implicit learning of vehicle performance.

The demonstration of implicit learning in simulated driving may, however, be of theoretical interest, both because it extends the scope of the control of complex systems paradigm, and also because it shows learning occurring in a context when the learner is consciously occupied with the diverse range of other tasks that driving entails. It is, therefore, much closer to a demonstration of implicit learning happening in the real world than most laboratory studies have been.

²⁸ With the caveat that, because of the within-participants design of this experiment, this absence of awareness was not confirmed by direct measurement but only *assumed*, on the basis that the performance difference was below the perceptual difference threshold (see following Methodology sub-section of this Discussion).

Methodology

In implicit learning studies it is generally considered necessary, in order to establish that implicit learning has occurred, to find a dissociation between measured performance (e.g. ability to control a process) and ability to verbally report the basis on which the behaviour was selected. Various authors (e.g. Shanks & St. John, 1994; Shanks, 2004) have critiqued such verbal reports as not necessarily sensitive to all aspects of the relevant conscious knowledge (and so in fact failing to establish a true dissociation). In a within-participants design, verbal reports are in any case problematic for reasons of demand characteristics: asking participants to make such a report during the first drive might influence what they attended to on subsequent drives: they might, for instance, attend more closely to available vehicle acceleration, and adopt explicit strategies to assess it, for instance by counting elapsed time to accelerate between certain speeds. For this reason, participants in Experiment 6 did not make verbal reports of the basis of their overtaking decisions; instead the design relied on the evidence from Studies 2 and 4, discussed above, that a difference in VA of 8% in the DigiCar simulator is too small to be perceived or verbally reported. An alternative for future studies might be to seek verbal ratings of the acceleration of the vehicle after each drive, but control for demand characteristic effects in the manner used in Experiment 2, by embedding these within a number of decoy questions relating to steering, braking, handling, etc., so that participants could not readily identify acceleration as the key experimental variable.

Of the 46 participants who successfully completed all four drives, eleven made no overtaking manoeuvres at all in Zone 5 and three others made only one or two. This suggests that for some drivers, even the *least difficult* overtaking difficulty condition (overtaking a four-vehicle train) was in fact perceived as too difficult by a substantial minority of participants. This suggests that in future studies of this kind, the minimum level of difficulty should be reduced.

In Experiment 6, the acceleration differences between conditions were too small for drivers to perceive them directly²⁹, but they nevertheless had an effect on participants' driving behaviour

²⁹ Again with the caveat that this was assumed, not measured directly, as discussed above.

(frequency of positive decisions to overtake). Drivers may be able to perceive these shifts in their own behaviour, and may interpret them by referring to themselves as feeling more “confident” about overtaking, as in Study 1. Over the course of a journey, these shifts may also have a perceivable impact on pursuit of journey goals, perhaps in the form of affective responses. Drivers might, for instance, be able to verbally report differences in how much “fun” it felt to drive different cars, even when unable to report the basis for these differences. Further research on this topic could explore these kinds of responses.

Implications for the design of electric vehicles

In Chapter Six I concluded that acceleration benefits of the size shown in Table 6-11 (7-11% over the 30-50mph speed range) would be sufficient to enable an EV to be perceived by most drivers as having better dynamic performance than a conventional ICE car of the same size in a direct comparison. Experiment 6, however, has shown that drivers’ behaviour can be affected by performance differences that are smaller than the perceptual difference thresholds, and I suggested above that these behaviour changes, or affective responses to them, might be perceived by drivers even when they cannot perceive the actual performance difference. This potentially gives the designer of a BEV more room to manoeuvre in making the trade-off between performance and range that I have already discussed. A BEV with an acceleration benefit (compared with an equivalent ICE car) that is below the perceptual difference threshold may still feel more “fun to drive” to a driver able to experience driving it for long enough to have implicitly learnt its performance, and used that learning in driving it. In Experiment 6, drivers appear to have acquired some implicit learning of their vehicle’s performance in less than 30 minutes (the approximate duration of the experimental drives).

Chapter Eight. The symbolism of vehicle performance: theory and literature

So far I have considered two perspectives on vehicle performance: first, how consumer drivers construe performance, and the specific attributes they see performance as having; and second, how specific attributes of performance, particularly acceleration, are perceived in driving (with a particular interest in the perception of *differences* in performance). From these two perspectives we are now able to understand what vehicle performance means to consumer drivers, and how they experience it. However to understand how the performance of low-carbon vehicles might influence their uptake, I need to consider it from a further perspective. Assuming that a low carbon vehicle differs from a conventional vehicle to a perceivable extent on some meaningful aspect of performance, we then need to ask, how much does that matter to the consumer? In other words, what value do consumers attribute to that performance difference?

Motivations for the acquisition and use of consumer products

Assuming consumers attach value to differences in vehicle performance, as I argued in Chapter 1, this should be reflected in their motivations³⁰ for car purchase and use. A starting point for understanding such motivations is the variety of theories of the social psychology of material possessions (Dittmar, 1992; Dittmar & Brown, 2008; Dolfsma, 2008; Fournier, 1991; Keller, 1993; Ligas, 2000; Park, Jaworski, & MacInnis, 1986).

Fournier (1991) argues that products are evaluated by consumers in terms of three dimensions: tangibility (from purely utilitarian to purely symbolic); emotional response (arousal or involvement: from un-engaging to emotionally involving) and meaning commonality (source of symbolic meaning: from widely socially shared to personally unique to the individual). Steg (2005)

³⁰ In the literature reviewed in this chapter, goals tend to be referred to as motives or motivations, without theoretical distinction, so the three terms will be used synonymously in the chapter.

has used Dittmar's social constructionist theory in several studies of car use. Steg's version of Dittmar's theory also has three dimensions of evaluation, but in this case the dimensions refer to qualitatively different categories of motivation for buying and using consumer goods: *instrumental*, *affective* and *symbolic*. The model of Park et al. has broadly the same three categories, referred to as *functional*, *experiential* and *symbolic*.

Instrumental or functional motivations for car use include such factors as cost, journey time, convenience, effort, carrying capacity, etc. (Steg, 2005). Individuals differ in the extent to which they experience instrumental benefits from owning or having access to a car with a particular combination of instrumental attributes. For some, instrumental benefits of car use are so great, and/or so difficult to achieve through other means, that they describe themselves as "car dependent" (Goodwin, 1997; Jeekel, 2013). Certain types of journey are commonly seen as highly car-dependent. Longer journeys at night, for instance, when public transport is often not available, can only be achieved by car (Jeekel, 2013). *Supermarket shopping* and *going away for the weekend* were rated as most dependent on the car in a general population survey in Scotland (Dudleston, Hewitt, Stradling, & Anable, 2005).

Vehicles clearly offer instrumental benefits, and instrumental motivations must play a significant role in most vehicle purchase choices. In fact many studies have assumed that instrumental motivations dominate vehicle choice. Models that assume choices are made on the basis on maximizing "utility", usually define utility in instrumental terms (Puttaswamaiah, 2002). A number of recent studies have investigated factors that influence consumers' deliberated choices between conventional and low-carbon or alternative-fuelled vehicles, using discrete-choice or hybrid-choice models and stated preference data (Adler, Wargelin, Kostyniuk, Kavalec, & Occhuizzo, 2003; Alvarez-Daziano & Bolduc, 2009; Brownstone, Brunch, & Train, 2000; Cheron & Zins, 1997; Dagsvik, Wennemo, Wetterwald, & Aaberge, 2002; Dimitropoulos, Rietveld, & van Ommeren, 2013; Funk & Rabl, 1999; Gould & Golob, 1998; Hackbarth & Madlener, 2013; Jensen, Cherchi, & Mabit, 2013; Lebeau, van Mierlo, Lebeau, Mairesse, & Macharis, 2012; Lieven, Muhlmeier, Henkel, & Waller, 2011; Thorgersen & Garling, 2001; Ziegler, 2012). Choo and Mokhtarian (2002) analysed eleven vehicle choice models and found that the focus in all of them was on

monetary costs and instrumentally-defined attributes. Performance has been included in such studies only in rather limited ways, using constructs such as “top speed” and “time taken to accelerate from 0-60mph”. Nevertheless they appear to show that consumers attach value to the instrumental benefits of vehicle performance³¹. In principle, the instrumental value of the performance attributes identified in Chapter Three could be studied in more depth using discrete choice methods (Train, 2009).

Affective, experiential or “hedonic” motivations (Hirschman & Holbrook, 1982) for product use are described as involving “sensory pleasure, variety, and/or cognitive stimulation” (Park et al., 1986). Some of the perceived benefits of car use that have been identified in qualitative research fall into this category: particularly enjoyment of driving as an activity in its own right (Gardner & Abraham, 2007). However there is reason to be sceptical about the conceptual validity of goals *to experience affect*. Modern social psychology conceptualizes behaviour in terms of the self-regulated pursuit of goals (Aarts & Elliot, 2009; Baumeister & Vohs, 2004; Carver & Scheier, 1998; Miller et al., 1960; Moskowitz & Grant, 2009; Powers, 2005; Wegner & Bargh, 1998). From this perspective, affect arises as a consequence of success or failure in goal pursuit (or, in Carver and Scheier’s (1998) goal-pursuit based theory of affect, as a consequence of low/high *rate of progress* in goal pursuit). Thus it makes little sense to speak of a goal to experience affect in and of itself: the affect must arise through the pursuit of some other goal. I therefore suggest that “affective goals” are post-rationalisations of non-conscious pursuit of other goals. Unaware of the actual goal being pursued, but conscious of the experience of affect, a person (erroneously) infers the goal of the behaviour to be the experiencing of that affect. Consider driving fast “for the thrill”, (Redshaw, 2008) apparently an affective goal. As I shall show in the next chapter, risky driving style is a signal of certain personality traits, and so serves *symbolic* goals; so the experience of thrill

³¹ However a cautionary note is necessary: although the methodology of choice experiments requires participants to make conscious choices, we cannot exclude the possibility that those choices are influenced, non-consciously, by symbolic goals.

is perhaps better explained as an affective response reflecting instantaneous high rate of progress towards a symbolic goal, pursued outside conscious awareness.

It is, however, well established that consumers acquire and use material goods in the pursuit of symbolic as well as instrumental motives (Belk, 1985; Dittmar, 1992; Dittmar & Brown, 2008; Fournier, 1991; Keller, 1993; Ligas, 2000; McCracken, 1988; Miller, 2009; Miller 2010; Park et al., 1986). Symbolic motives concern signalling something about the owner/user to other people, such as personal identity (Dittmar, 1992; McCracken, 1988; Miller, 2009; Sirgy, 1982a,b; Sirgy, 1985; Tucker, 1957) status (Griskevicius, Tybur, Sundie, Cialdini, Miller, & Kenrick, 2007; Nelissen and Meijers, 2011; Sundie, Kenrick, Griskevicius, Tybur, Vohs, & Beal, 2010; Veblen, 1899) or social category membership (Dittmar, 1992; McCracken, 1988). Possession or use of material goods conveys such signals because goods carry symbolic meaning – i.e. they *stand for* something else. To be effective as means to fulfil symbolic goals, their meanings must be shared by the possessor/user and by his/her “audience” – those people, in social groups or in a wider cultural sense, to whom something is signalled. These socially or culturally defined meanings are then used by the individual to express something about themselves (Dittmar, 1992; McCracken, 1988; Mick, 1986; Miller, 2010).

Although the instrumental value of vehicle performance is well established, its symbolic value has hardly been studied. Armed with a clear picture of how vehicle performance is construed by consumer drivers, I can now explore its symbolic value in depth. A product has symbolic value to the extent that its possession or use supports the pursuit of a symbolic goal: i.e. to the extent that it holds symbolic meanings that can act as effective signals of something a person is motivated to signal. Symbolic meanings confer the symbolic value that products have for the pursuit of symbolic goals. Thus, the key to understanding the symbolic value of vehicle performance attributes is to identify their symbolic meanings.

Symbolic meaning and semiotics

Symbolic meaning, or, more generally, the study of signs, is the domain of semiotics (Berger, 2010; Chandler, 2007; Csikszentmihalyi & Rochberg-Halton, 1981). A full summary of concepts in semiotics is beyond the scope of this review (Chandler, 2007, provides an accessible introduction; Holbrook and Hirschman, 1993, and Mick, 1986, specifically consider the semiotics of consumption). However a few basic concepts will inform the discussion.

A symbol can be thought of as something that stands for, or represents, something else (Chandler, 2007). Symbols are important tools for communicating with others, and indeed, language is a set of symbols (words) whose meanings are shared (Saussure, 1916). Symbols need not be words, however. Images can serve as symbols (brand logos, for instance), and likewise so can objects. The symbolism of an object such as a national flag is perhaps rather obvious; but any object, including any consumer product, can be a symbol.

Semiotics developed from the work of Saussure (1916) and Pierce (1931), which led to two distinct schools. Saussure defined a “sign” as a two-part (dyadic) system, comprising a *signifier*, and a *signified*. Modern semioticians describe the signifier as the form that the sign takes, and the signified as the concept to which it refers³². Signifier is thus the technical term for what has been informally referred to so far as a symbol³³.

³² The dyadic model has earlier origins: it has been used as far back as the late Roman writings of St. Augustine (397).

³³ Strictly speaking, in semiotics a “symbol” is a specific kind of signifier, which does not resemble the signified, but is arbitrary, so that the signifier-signified relationship must be learned. There are other modes of relationship. In the iconic mode, the signifier bears some resemblance to the signified, possessing some of its qualities; and in the indexical mode, the signifier is directly connected to the signified (for instance, smoke signifying fire) (Chandler, 2007).

One example of a sign is a company logo (the signifier) and the company's brand image in consumers' minds (the signified); another might be the latest iPhone, (the signifier), symbolizing aspects of its owner's identity (the signified), for instance that its owner is open to new technologies and is adept at using them. The "signified" in Saussurean theory is not a material thing in the world, but rather a psychological concept in the mind of the person perceiving the sign. Saussure argued that signs only make sense as part of a formal, abstract system (Chandler, 2007). Thus the meaning of a sign was seen as lying in its relationships to other signs in a complex system, rather than in referring to a material thing.

Pierce (1931) developed an alternative, triadic model of the sign, comprising three parts:

The *representamen*: the form the sign takes (somewhat similar in meaning to Saussure's signifier).

The *interpretant*: the interpretation or sense made of the sign by the person perceiving it.

The *object*: Something beyond the sign itself, to which the sign refers.

In Pierce's model, a sign thus comprises what is represented (object); how it is represented (representamen); and how it is interpreted (interpretant). Pierce's model thus places more emphasis on its property of reference to an object in the world.

Although iconic or indexical signs may bear some sensory resemblance to the signified or an aspect of it, the meanings of *symbols* are arbitrary and socially constructed. All that it takes for a symbol to have a particular meaning is that people agree that it has that meaning. Some symbols may have a meaning shared across a whole culture, or even globally. The meaning of others might be shared among only a small social group, or might be contested by different groups; and a symbol may have a particular personal meaning that is not shared, but unique to one individual. From a Saussurean perspective, these socially constructed meanings only make sense by reference to a system of other socially constructed and shared meanings.

In this research, my interest is more in shared than individual meanings. The research question is whether aspects of vehicle performance have symbolic meanings, and if so, what those meanings are and how widely they are shared.

Acquisition and use of consumer products in pursuit of symbolic goals

A product has symbolic value to the extent that its acquisition or use supports the pursuit of a symbolic goal (because it has symbolic meanings that can act as effective signals of something a person has a goal to signal). There have been a variety of approaches to understanding symbolic goals for the acquisition and use of consumer products. In *self-congruity theory* (Sirgy, 1982a; 1982b; 1985) people are motivated to behave in ways that are congruent with their self-concepts, so they buy products whose meanings are consistent with it. The meanings associated with products involve stereotypes of a typical user, so they communicate information about the sort of person likely to use them. Several empirical studies of car ownership provide support for Self-congruity theory (Eriksen, 1996; Grubb & Stern, 1971; Heath & Scott, 1998; Sirgy, 1985). Self-concept is, however, seen as multi-dimensional, with components including actual self, ideal self, social self, and ideal social self (Sirgy, 1982b; 1985; Sirgy & Danes, 1981). Thus a given consumer product might be acquired for reasons of congruity with one or more of several “selves”.

Symbolic interactionism (Blumer, 1937; Solomon, 1982) also views the individual as having multiple selves, in this case each representing a *role* (how the individual behaves in a particular social setting). Selves are defined through interaction with others; a particular self is constructed from how the individual imagines he/she is seen by others in a particular social setting (Cooley, 1902). When an individual is experienced in a particular social role, products are used to symbolize the role (Solomon, 1982). For instance, having a multi-purpose vehicle (MPV) could act as a symbol of the role of parent. However when the individual is unfamiliar with a role, products serve a different purpose: they shape the individual’s portrayal of her/himself, and help to define the role (and the associated aspect of the self-concept). For example, having a car can help young people portray and define themselves as adults.

Symbolic self-completion theory (Wicklund & Gollwitzer, 1982) proposes that goods are one form of a range of symbols that are adopted and used to complete a person’s self-definition. *“Deficiencies in symbols of one’s accomplishments, in regard to a particular self-definition, create the motivation to pursue further evidence of possessing the self-definitional quality”* (Wicklund &

Gollwitzer, 1982, Preface, p.x). Possession of a sports car, for instance, might serve a self-completion goal by providing evidence of masculinity.

Vignoles, Regalia, Manzi, Gollege, and Scabini (2006), in a review of literature on the self, identified six different identity-related motives: constructing and maintaining self-esteem, continuity, distinctiveness, belonging, efficacy, and meaning. Shrum et al. (2013) re-conceptualised “materialism”, which they defined as *“the extent to which individuals attempt to engage in the construction and maintenance of the self through the acquisition and use of products, services, experiences or relationships that are perceived to provide desirable symbolic value”* (p.1180) in terms of the simultaneous pursuit of these multiple identity goals. They argued that the relative importance of these different goals varies between people, and also across time and situation within the same person. Importantly they also argued that the “audience” for symbols of identity could include oneself as well as other people (Chaplin & John, 2007; Dhar & Wertenbroch, 2012; Miller, 2009; Richins, 2011). For example, purchase of expensive cars can support fulfilment of the goal to maintain self-esteem by self-signalling that one has high status: expensive cars are seen as status symbols (Eastman, Goldsmith, & Flynn, 1999; Waldorp, 1989).

Shrum et al. recognised that the six identity goals of Vignoles et al. (2006) are not an exhaustive list, citing Deci and Ryan (2000), Kenrick, Giskevicius, Neuberg, and Schaller (2010), and Maslow (1943) for examples of a wider range of goals that may be pursued through materialistic behaviours. Conspicuous consumption, the acquisition and display of (luxury) goods as a public signal of economic success, status and prestige (Veblen, 1899), has been shown to fulfil various wider goals. Nelissen and Meijers (2011) found that conspicuous consumption (operationalised as the wearing of luxury-branded versus non-branded clothes), elicited preferential treatment in a range of social situations, including willingness to comply with requests, or donate to a charity, evaluations of suitability for a job, and cooperativeness in a social dilemma. Conspicuous consumption has also been shown to be adopted strategically in the service of social affiliation goals as a result of perceived social exclusion (Lee & Shrum, 2012; Mead, Baumeister, Stillman, Rawn, & Vohs, 2010) and perceived powerlessness (Rucker & Galinsky, 2008; 2009).

An important additional perspective, grounded in evolutionary theory, is that material goods are acquired and used in the pursuit of mating goals (Griskevicius et al., 2007; Miller, 2009; Penn, 2003; Saad, 2007; Sundie et al., 2010). From this perspective, conspicuous consumption is conceptualised as a sexually selected mating tactic. Sexual selection (Darwin, 1871) refers to the process by which conspicuous traits are selected for, through mate choice, because they act as costly signals of reproductive fitness. A familiar example is the peacock's tail, which signals that the peacock has the physical resources and disease immunity to thrive while burdened by such a handicap (Zahavi & Zahavi, 1997), and thus would be capable of producing high reproductive quality offspring. In conspicuous consumption, males signal resource-holding power (wealth) to attract females (Buss, 1989; Shackelford, Schmitt, & Buss, 2005; Stewart, Stinnett, & Rosenfeld, 2000; Townsend & Wasserman, 1998); and expensive goods act as reliable signals, precisely because less wealthy males could not afford them. Griskevicius et al. (2007) demonstrated this experimentally, showing that in a mating-primed context, men would be willing to expend extra on goods that they might use publically, but not on goods that would not be seen by others.

Sundie et al. (2010) found a somewhat more complex picture in which conspicuous consumption is driven by men pursuing *low-investment* mating strategies (seeking casual, non-involving relationships), and is triggered by the activation of short-term mating goals. They also found that such signals are accurately interpreted by observers, and that women perceive conspicuous consumption by men as enhancing their short-term (but not long-term) mating desirability. The converse was not found to be true: women did not engage in conspicuous consumption in response to activation of short-term mating goals, nor did it enhance their desirability to men as short-term mates. Further evidence comes from studies showing that males reported higher valuations of material wealth after exposure to potential mates, in person or in photographs (Roney, 2003); male testosterone levels increased after driving an expensive sports car but decreased after driving an old sedan (Saad & Vongas, 2009); women rated the same man as more physically attractive when seated in a prestige car than a neutral status car (Dunn & Searle, 2010) although there was no effect on the attractiveness of women to men; and young male drivers adopted more dynamic driving

styles in the presence of a female passenger (Skippon et al., 2012)³⁴. On the other hand, Griskevicius et al. (2007) found that activation of mating goals led to women engaging more in “blatant benevolence”, a public signal of helping and attending to the needs of others.

This pattern of findings can be understood in terms of life history theory (Kaplan & Gangestad, 2005; Stearns, Allal, & Mace, 2008), which seeks to explain how an animal’s life cycle is shaped by natural and sexual selection for reproductive success. Since organisms have finite resources, they must allocate them strategically between somatic effort (building and maintaining a functional body), mating effort, and, in some species, parenting effort. The majority of conspicuous displays in nature are found in males (Darwin, 1871). This is a result of sex differences in the minimal parental investment (Trivers, 1972) required to produce viable offspring. Gangestad and Simpson (2000) proposed that humans vary in how far they pursue low-investment mating strategies versus high-investment mating strategies (seeking long-term relationships, in which both partners can contribute parenting effort), depending on desirability to the opposite sex and current economic and other environmental conditions. Males tend to move from low-investment to higher-investment strategies as they mature, while females (from whom reproductive biology automatically requires high minimum parental investment) tend towards higher investment strategies; though neither pattern is exclusive, particularly in modern societies. These alternate strategies are reflected in mate choice preferences (Simpson & Gangestad, 1992).

While most research from an evolutionary perspective has focused on the use of products as signals of status, Miller (2009) has proposed that goods also signal a wider set of meanings. Nettle and Clegg (2007) had argued that variations in human behaviours, attitudes and reproductive fitness reflect the five main dimensions of the five-factor model of personality. Miller suggested that

³⁴ However note that Skippon et al.’s finding, from a controlled experiment in a driving simulator, contrasts with the finding by Waylen & McKenna (2002) that young male drivers with male passengers were observed using more dynamic styles, but not young male drivers with female passengers. As the latter was an observational study in which activation states of goals were not known, this contrast perhaps suggests that context is likely to be important.

consumers are motivated to acquire and use goods that signal the user's five-factor personality traits and general intelligence, because these traits function as reproductive fitness indicators. Thus the principal symbolic meanings of products are the users' personality traits and intelligence. Other meanings are interpreted, from this perspective, as the specific ways in which a product signals these ultimate meanings.

In Miller's theory, sexual selection processes have led humans to have heritable dispositions to signal their reproductive fitness, via costly signals of their personalities and general intelligence. However this does not imply that consumers consciously consider the impact on their reproductive fitness, or what signals about personality and intelligence they may be sending, when buying a watch, a dress, or a car. There is ample evidence for the non-conscious, unintentional communication and perception of personal traits (Choi, Gray, & Ambady, 2005). Miller's theory merely implies that people will experience it as rewarding to purchase and use consumer goods that send such signals.

Miller's theory does not specify the mechanism by which a particular product comes to have its specific meaning in terms of personality traits and intelligence: that remains a matter of social construction. McCracken (1988) proposed a model of the movement of meaning, in which the meaning of goods resides in three types of location. The first location is the "*culturally constituted world*", the world "*of everyday experience in which the phenomenal world presents itself to the senses of the individual, fully shaped and constituted by the beliefs and assumptions of his or her culture*" (pp. 72-73). Meaning resides here in the form of cultural categories and cultural principles. The second location is in the goods themselves (in terms of the culturally understood categories they come to signal), and the third is in the possessors/users of the goods (in terms of the culturally understood categories that possession or use signals about them to other people). The model also includes processes that move meaning between these locations. For example, goods often come to be imbued with meaning because marketers actively choose cultural categories, available within the culture of their product's market, with which they seek to associate their products, and create such associations through advertising. Costly signalling theory suggests an extension to this model, which I introduce in Figure 8-1.

This involves the addition of a further location in which meaning resides: the human traits that confer reproductive fitness on those who possess them. It also includes an additional meaning movement process, in which those traits are recognized, shape the beliefs and assumptions of the culture, and become embedded in the system of categories available within that culture. Thus costly signalling theory provides an evolutionary rationale for the existence of some cultural categories. Meaning movement between culture and particular goods, however, remains best understood as a process of social construction. Perhaps this is a rare occasion when these two often fiercely contested theoretical perspectives can co-operatively account for a social phenomenon.

Miller’s theory provides the basis for a well-defined framework to analyse the symbolic meaning of any consumer product: it can be defined as what the product signals to others about the user’s five-factor personality and general intelligence. In the next chapter I shall discuss a novel experimental paradigm for measuring symbolic meaning within this framework, and apply it to the meanings of cars, their performance, and the ways they are used - driving styles.

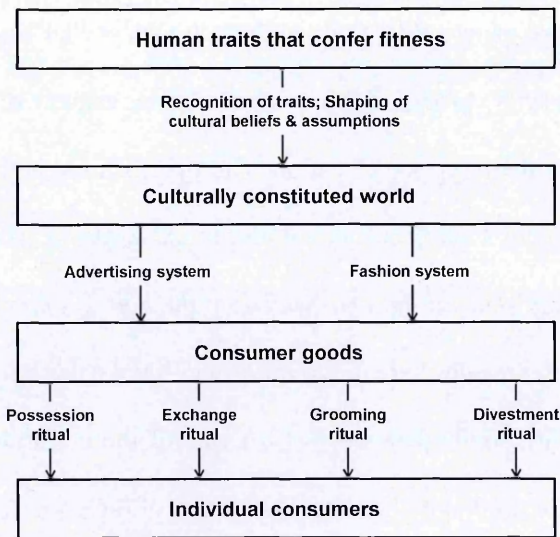


Figure 8-1. Extended version of McCracken’s model of meaning movement

Chapter Nine. The symbolic meaning of cars, their performance, and driving: costly signals of reproductive fitness?

I now set out to investigate the symbolic meaning of vehicle performance as it is construed by consumer drivers – what each of the key aspects of dynamic and cruising performance identified in Study 1 say about someone who uses a car that exhibits them. To do so I shall make use of Miller's (2009) theory, and characterize symbolic meaning in terms of what each aspect of performance signals about the personality traits of the user.

Although there is now a body of research showing that products can signal status and other aspects of identity (reviewed in the previous chapter), there has to date been little that investigates whether, or how far, products can specifically signal five-factor personality traits. Therefore, before attempting to characterize the symbolic meanings of specific *attributes* of cars, I shall begin in Study 7 by first characterizing the symbolic meanings of different types of cars themselves, as products. This will also enable me to explore how the symbolic meanings of performance attributes fit within the broader context of cars as symbols - taking the Saussurean perspective that socially constructed meanings only make sense by reference to a system of other socially constructed and shared meanings.

The re-conceptualisation of materialism as the pursuit of identity goals by Shrum et al. (2013, p.1180) emphasised the “acquisition *and use* of products, services, experiences or relationships that are perceived to provide desirable symbolic value” (my italics). However most research on symbolic meaning has focused on the meaning of products, rather than the meaning signalled by the ways in which they are used. As I have shown in earlier chapters, there are substantial individual differences in one aspect of the way people use cars, their driving style, which correlate with five-factor personality traits. Study 8, therefore, aimed to investigate the symbolism of car *use*, and explore how far such symbolism is consistent with the symbolism of cars themselves.

Study 9 then used the same methodology to investigate the symbolic meaning of vehicle performance. Although there has been research on the symbolism of ensembles of products

(Dittmar, 1992), particularly ensembles of clothing (McCracken, 1988) there has been little investigation into how symbolic meaning is carried by specific product attributes. The methodology of choice experiments (Train, 2009) assumes that products can be described by a finite number of attributes, and that consumer purchase choices depend on the particular combination of these attributes that a particular product possesses. As outlined in Chapter Eight, choice experiments tend to assume implicitly that choices are made on the basis on maximizing “utility”, define utility in instrumental terms, and include only attributes that are instrumental in nature. Recognition that people acquire products to fulfil symbolic goals challenges these assumptions, and suggests that specific product attributes such as the dynamic or cruising performance of a car may have value because they convey all, or part, of the symbolic meaning usually attributed to the product as a whole.

Measuring symbolic meaning

The study of symbolic meaning is traditionally the domain of semiotics and cultural anthropology, and the principal approach has been to elicit those meanings from consumers through qualitative interviewing. For example, Heffner et al. (2007) used qualitative interviews to investigate the symbolism of the first hybrid electric cars in California in the early 2000s. However the qualitative interview approach has limitations. First, it can explore only those meanings of which participants are consciously aware. Second, it is susceptible to socially acceptable responding: participants may be reluctant to discuss aspects of their beliefs, attitudes, and behaviours that they think would present them in a bad light (Robson, 2002). Third, the meanings elicited may be too context-specific: generalisation and comparisons can be difficult from small-sample qualitative studies (Robson, 2002; Willig, 2012) so the meanings of products elicited in such a study may not be representative of their meanings within their wider culture.

In Studies 7-9, I used an alternative methodology, based on attribution theory (Försterling, 2001; Hewstone, 1989; Jones & Davis, 1965; Kelley, 1967), that avoids some of these difficulties and provides a tangible, quantitative measure of symbolic meaning. Attribution theory proposes that when an observer perceives another person, an actor, carrying out a behaviour, the observer will

tend to attribute the behaviour to a dispositional cause – i.e. locate the explanation for the actor's behaviour in the personality of the actor. The experimental paradigm was therefore based on the assumption that when one person (observer) observes another person (actor) possessing or using a consumer product (behaviour), the first person will infer from that behaviour that the second has certain traits (attribution). These traits will be those that the observer associates with the product – in other words, the symbolic meaning of the consumer product. Attribution theory has often been studied using vignette experiments. The experimental paradigm used this method: participants are presented with short vignettes related to the product, after which they are asked to imagine the typical user of a product, and to make attributions about that user. I shall therefore refer to it as the “attribution-vignette” method.

Attributions were made using a short questionnaire, which contained items relating to the five-factor personality traits of a typical user of the product. The existence of reliable, validated instruments to measure five-factor personality traits, such as NEO PI-R (Costa & McCrae, 1992; 1995), NEO-PI-3 (McCrae, Costa, & Martin, 2005), IPIP-NEO (Goldberg et al., 2006), and also very short instruments, which take only a minute or so to complete (Gosling, Rentfrow, & Swann, 2003; Nettle, 2007; Rammstedt & John, 2007) is a strength of the methodology. Personality traits in Studies 7-9 were measured using an adapted sub-set of items selected from IPIP-NEO.

In addition, the questionnaire included items to measure attributions of status, gender, age, relationship investment and physical attractiveness, which the costly signalling literature reviewed in Chapter Eight suggests might also be salient to the pursuit of symbolic goals related to signalling reproductive fitness.

However I did not include a measure of attribution of general intelligence, as Miller's theory would suggest. While not challenging Miller's proposal that consumer goods signal general intelligence, its measurement is sometimes controversial, its technical meaning is contested within the research community, and its technical meaning is different from the informal meanings of “intelligence” in everyday discourse. In addition, the author is unconvinced of the cross-cultural validity of general intelligence measures developed mainly for use within developed-world (and particularly US) cultures. It did not seem appropriate, therefore, to use it in these studies.

Given the socially constructed nature of symbolic meanings, the meanings of categories of cars might vary among social groups. Several authors, for instance Dittmar (1992), have emphasised this possibility in respect of gender and socio-economic status. To explore this, the results were also analysed in terms of participant gender, age and socio-economic group³⁵.

Study 7: The symbolic meaning of cars

Study 7 was designed to test the hypotheses: (a) that people can make attributions of personality traits to the user of a car, based only on knowledge of the category of car he/she is using; and (b) that the attributed personality traits are different for different categories of car. In addition, Study 7 measured attributions of status, gender, age, relationship investment and physical attractiveness, testing similar hypotheses to those concerning personality traits. It was also designed to map the range of variation of symbolic meanings across the major categories of cars.

Method

Participants

Participants in Study 7 were UK residents from multiple locations around England, Scotland and Wales, distributed among socio-economic categories in proportion to their incidence in the general population, recruited from a market research panel. None were also participants in Studies 8 or 9. Of the 1009 participants, 517 were women (492 men); 396 were aged 35 or under (613 were 36 or over); and 562 were members of socio-economic groups A, B and C1 (447 were members of socio-economic groups C2, D or E). The mean age of the sample was 40.6 ± 12.9 years.

³⁵ Socio-economic group (SEG), categorised as A, B, C1, C2, D or E using the NRS classification scheme familiar to UK marketers and market researchers. See Appendix 2 for details.

Procedure

On each trial the participant was shown an image of a car, asked to imagine a person who would normally use that car, and then asked to answer a series of questions about the user.

Stimuli

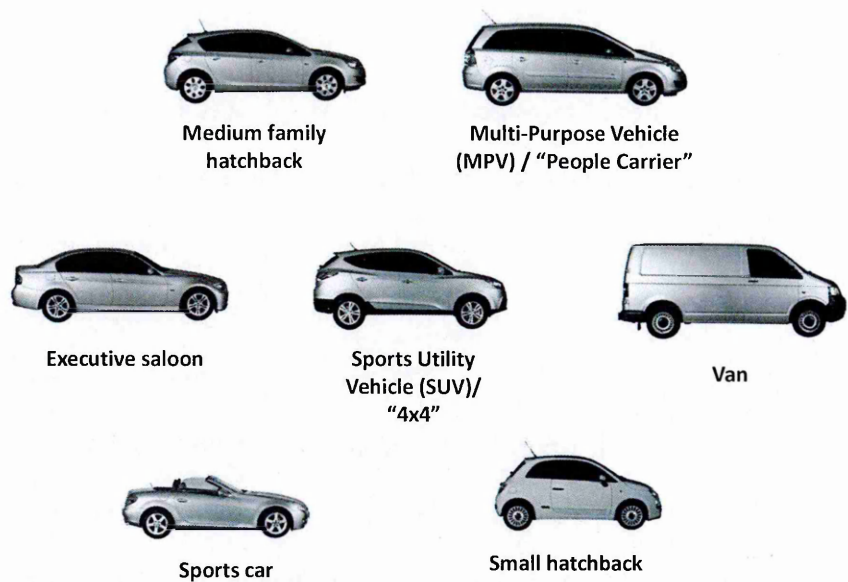


Figure 9-1. Study 7: Categories of vehicles and vehicle images used to represent them

Seven different images were provided, each representing a different major category of car or van (Figure 9-1). The categories were similar to those used as elements in the repertory grids of Study 1 (Chapter Three), except that there was a single category of medium family hatchback (rather than distinct gasoline and diesel versions, as it is difficult to distinguish these via images). Images were presented in grey-scale, with image tones edited to ensure similar overall brightness, contrast, and distribution of tones in the bodywork. Windows were blacked out, and brand identifiers were removed³⁶, as brands might have confounding associations, independent of car category.

³⁶ As far as possible – though some degree of explicit or implicit brand recognition from vehicle shape, etc. remained possible.

Measures

Attributions were assessed using 18 items presented after each image (see Table 9-1 for the full list). Participants were asked to indicate how accurately each item would fit the person they imagined would normally use the car. Participants' responses were recorded using five-point Likert-type items with verbal anchors for each point (1 = doesn't fit the driver; 2 = only fits the driver a little; 3 = fits the driver moderately; 4 = fits the driver well; 5 = fits the driver very well). The order of presentation of the images and of the response items was randomised between participants. Ten of the items measured attributions of the five-factor personality traits conscientiousness, openness, extraversion, agreeableness, and neuroticism (Costa & McCrae, 1995; McCrae & Costa, 2003). Each trait was represented by a pair of items, one positively valenced with respect to the trait and the other negatively valenced. The items were selected from the 120-item version of the IPIP-NEO personality inventory (Goldberg et al., 2006). For each trait factor, the two individual items were selected that had the highest correlations with that trait factor in an earlier survey using the inventory. Two of the pairs of items, as taken from IPIP-NEO, had the same valence with respect to their traits. Accordingly one item in each of these pairs was modified from its original IPIP-NEO form in order to reverse its valence. The other eight items measured attributions of status, gender, age, relationship investment and physical attractiveness.

Data analysis

The personality traits of an individual are usually measured in relation to the distribution of those traits within some reference population. The distribution of scores is recorded for a large sample drawn from the population, known as a "norm" group, and individual responses are expressed as percentile or z-scores relative to the norm group mean. There exist published norm group data for IPIP-NEO (as for all the major five-factor inventories). In the attribution-vignette method, however, I was not seeking to characterise the personality profile of an individual relative to other people, but rather to identify the symbolic meaning of a product relative to the meanings of other symbols in the symbol system of which it is part (where those meanings are expressed in terms of the personality traits of typical users of the product). Thus, the appropriate comparison group is the distribution of traits signalled by the symbol system, rather than the distribution of traits in a

population of people. Accordingly, in this study, the assumption was made that the range of symbolic meanings of the vehicle categories shown to participants was representative of the diversity of meanings in the symbol system as a whole. On that basis, overall means and standard deviations of the 7063 total responses for each attribution item were used as norms to transform the raw scores to z-scores. The consequence of this approach was that all the data were transformed into relative measures: the attribution, of, say, conscientiousness to the user of a particular type of vehicle was measured relative to the distribution of attributions made in relation to all vehicle categories.

Analysis of Likert-type data using parametric statistics relies on an assumption that the data are interval in nature. This assumption is often difficult to justify, and many researchers simply gloss over the fact they have made it because of the convenience and familiarity of parametric analysis. Z-score scales, however, have the merit that their intervals have defined meaning (position in the overall distribution that defines the norms), and constant value; which makes the use of parametric statistical methods reasonable. Accordingly, the z-score data were analysed using a mixed factorial ANOVA with two within-participants variables (vehicle category and item) and three between-participants variables (gender, age, and socio-economic group).

Results

Table 9-1 shows the mean z-score for each item and each vehicle category, averaged for all participants. Mauchy's test for sphericity was significant, indicating that variances between the differences in combinations of levels of the independent variables were unequal, so the Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) was applied to the degrees of freedom in the ANOVA³⁷. There was a significant item \times vehicle category interaction: $F(50.976, 51026.782) = 182.20, p < 0.001$, indicating that mean responses to each item varied depending on

³⁷ Following the guidance of Girden (1992) for $\epsilon < 0.75$.

vehicle category. Partial eta squared was 0.154, indicating a large effect size (Cohen, 1988)³⁸. The average range (variation in responses to that item) across vehicle category was 0.85. The lowest range, 0.19, was for the item “feels uncomfortable around people”, the negatively-valenced item relating to the personality trait of extraversion; while the highest range, 1.56, occurred with the item “is female”, suggesting that vehicles conferred particularly strong signals about user gender.

Item	Mean z-score for each vehicle category						
	Family hatchback	Exec saloon	SUV	Sports car	Van	Small hatchback	MPV
Likes to tidy up	0.16	0.04	-0.01	-0.13	-0.60	0.19	0.32
Makes rash decisions	-0.15	-0.06	0.20	0.55	0.20	-0.13	-0.33
Sees beauty in things that others might not notice	0.17	0.00	-0.01	-0.08	-0.36	0.36	0.17
Prefers to stick to things that he or she knows	0.09	0.13	-0.09	-0.36	-0.04	-0.03	0.24
Has a lot of fun	-0.04	-0.24	0.07	0.66	-0.27	0.09	-0.28
Feels uncomfortable around people	0.10	-0.07	0.03	-0.09	0.05	0.00	-0.03
Sympathises with the homeless	0.22	-0.24	-0.11	-0.41	-0.10	0.41	0.29
Gets back at others	-0.23	0.25	0.17	0.37	0.20	-0.31	-0.32
Feels able to deal with things	-0.12	0.28	0.00	0.19	-0.20	-0.32	-0.04
Worries about things	0.07	0.04	-0.10	-0.37	-0.16	0.21	0.32
Has a low status job	0.21	-0.40	-0.19	-0.33	0.60	0.44	0.07
Has a high income	-0.28	0.60	0.44	0.66	-0.73	-0.71	-0.12
Is female	0.09	-0.30	0.05	0.00	-0.88	0.68	0.30
Is aged 35 or under	0.04	-0.30	-0.07	0.32	-0.06	0.35	-0.17
Frequently has casual sexual relationships	-0.17	0.05	-0.03	0.75	0.18	-0.07	-0.53
Is in a long term relationship with a spouse or partner	0.13	0.18	0.13	-0.58	-0.37	-0.33	0.61
Is physically attractive	0.01	0.07	0.02	0.36	-0.48	0.05	-0.11
Is physically unattractive	-0.06	0.09	0.04	-0.04	0.26	-0.13	0.06

Table 9-1. Study 7: Mean z-scores for each item & each vehicle category: all participants

³⁸ With very large sample sizes like those in the studies in this chapter, statistical significance can be achieved for small effect sizes of little psychological significance. However results of inferential tests are included in addition to effect sizes for thoroughness.

In Figures 9-2 and 9-3, the data from oppositely-valenced pairs of items are combined to provide overall measures of each personality trait, status, relationship investment and physical attractiveness. The single-item measures of age and gender are repeated in Figure 9-3, so the two figures provide a comprehensive summary of the results. Vehicle category appeared to provide a signal of all five personality traits, and was a particularly effective signal of agreeableness and conscientiousness (which exhibit the largest variation across vehicle categories). It was also a signal of age, physical attractiveness, gender, relationship investment, and status; particularly the latter three.

The results indicate that using a small hatchback signalled to others that the user was around average in extraversion, a little above average in conscientiousness, and moderately above average in openness, neuroticism and agreeableness. The small hatchback also provided a weak signal that its user was physically attractive and had low relationship investment, a moderately strong signal that the user was young, and strong signals that the user was female and had relatively low status.

Using a sports car, on the other hand, signalled to others that the user was a little above average in openness, above average in extraversion, and below average in neuroticism, conscientiousness and agreeableness. The sports car signalled nothing about the gender of its user, provided a moderate signal that its user was physically attractive and young, and provided strong signals that its user had high status and low relationship investment.

Figures 9-4 and 9-5 show how attributions from male and female participants differed. There was a significant item \times vehicle category \times participant gender interaction: $F(50.976, 51026.782) = 3.604$, $p < 0.001$, though the effect size was small (partial eta squared = 0.004). Broadly, men's and women's attributions tended to be consistent, and in almost every case they were in directional agreement. However they sometimes differed in strength: for instance, female participants attributed lower agreeableness and neuroticism, higher extraversion, and higher status, physical attractiveness and youth to users of a sports car than did male participants.

Similarly, attributions by older and younger participants (Figures 9-6 and 9-7) were broadly consistent, with some differences in strength in relation to particular vehicle categories (for

instance executive saloon and sports car). The item \times vehicle category \times participant age group interaction was significant: $F(50.976, 51026.782) = 4.221$, $p < 0.001$; though the effect size was again small (partial eta squared = 0.004).

Finally, attributions by participants of higher and lower socio-economic status (Figures 9-8 and 9-9) were also broadly consistent, with some differences in strength (for instance, although both groups attributed low status to a van user, lower status participants attributed less low status in this case). The item \times vehicle category \times participant socio-economic group interaction was significant: $F(50.976, 51026.782) = 1.658$, $p < 0.001$; though the effect size was small (partial eta squared = 0.002).

Discussion

The results supported both of the Study 7 hypotheses, showing that people can make attributions of five-factor personality traits to a vehicle user based on knowledge of the category of vehicle he/she is using; and that the attributed personality traits are different for different categories of vehicle. Attributions can also be made in respect of the status, gender, age, relationship investment and physical attractiveness of users of vehicles, and again, these attributions clearly differ by vehicle category. What is more, there is a broad consistency in people's attributions.

It follows that vehicle category can act as a social symbol of personality, status, gender, age, relationship investment and physical attractiveness. To the extent that vehicles usually require substantial expenditure on the part of their users (capital outlay, for an owner/user; and operating costs, including lease or hire charges for a non-owner), they can also serve as *costly* signals of these traits.

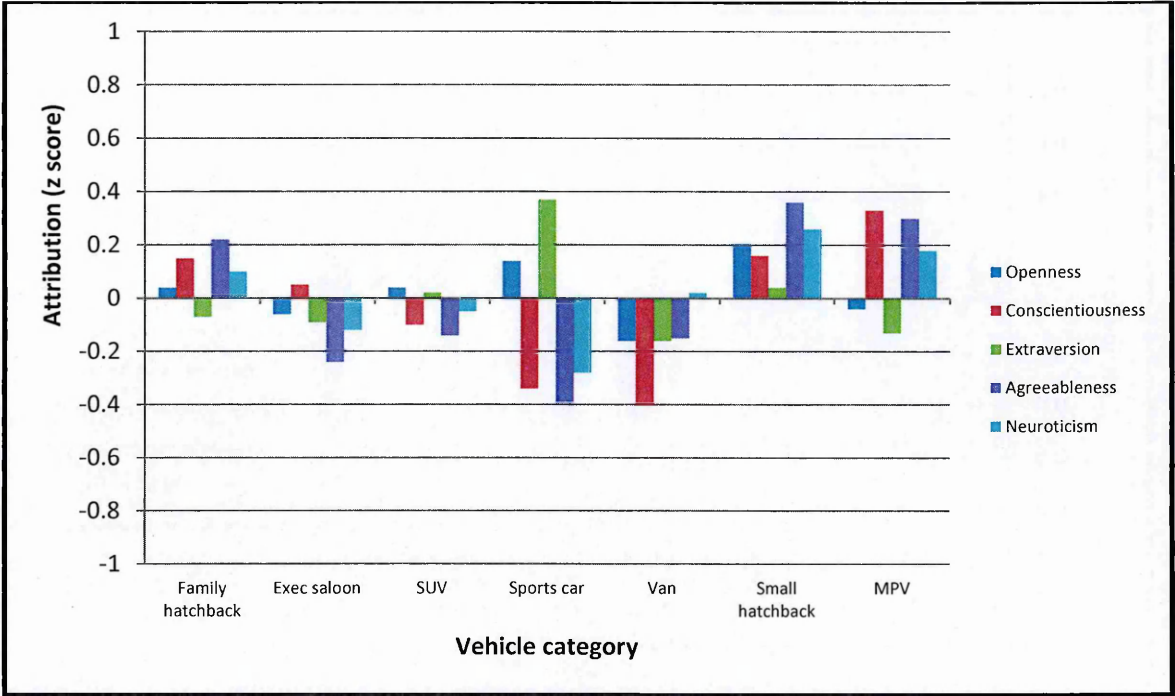


Figure 9-2. Study 7: Personality traits attributed to users of each vehicle type by all participants

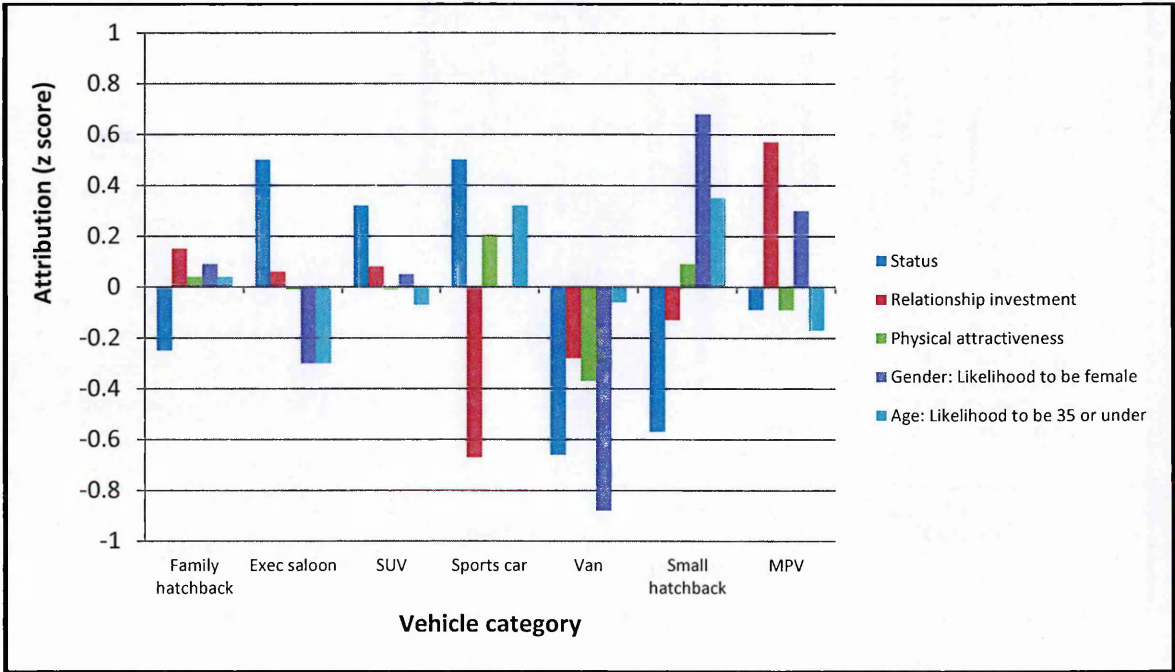


Figure 9-3. Study 7: Status, gender, age, relationship investment and physical attractiveness attributed to users of each vehicle type by all participants

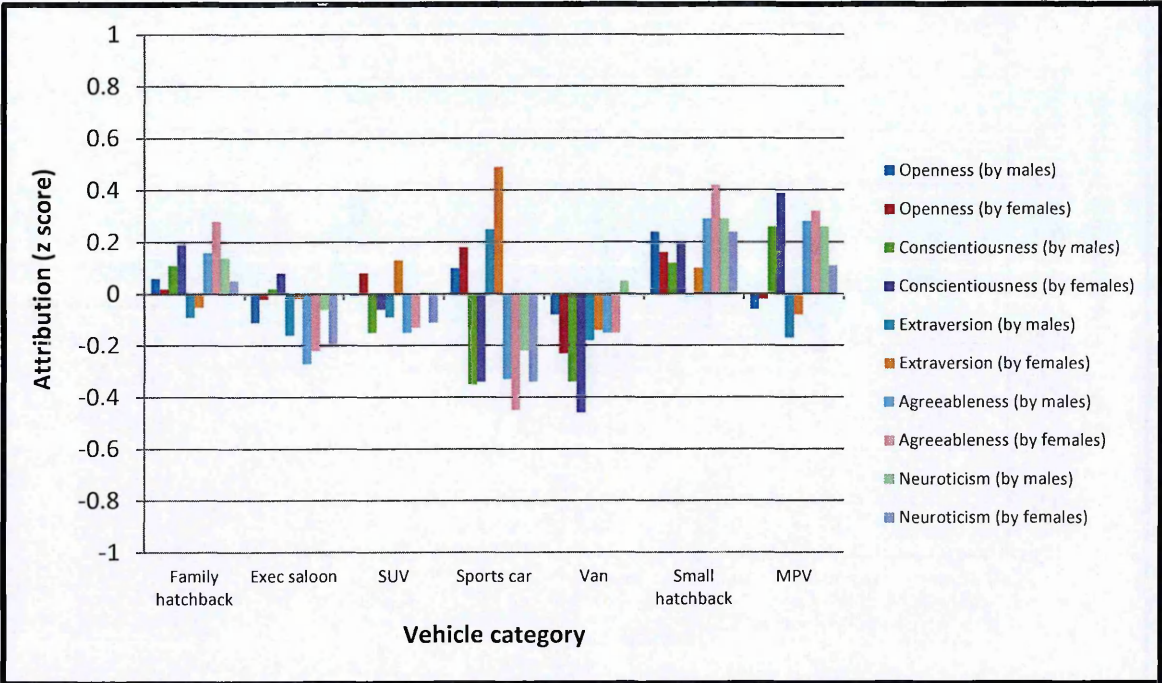


Figure 9-4. Study 7: Personality traits attributed to users of each vehicle type by male and female participants

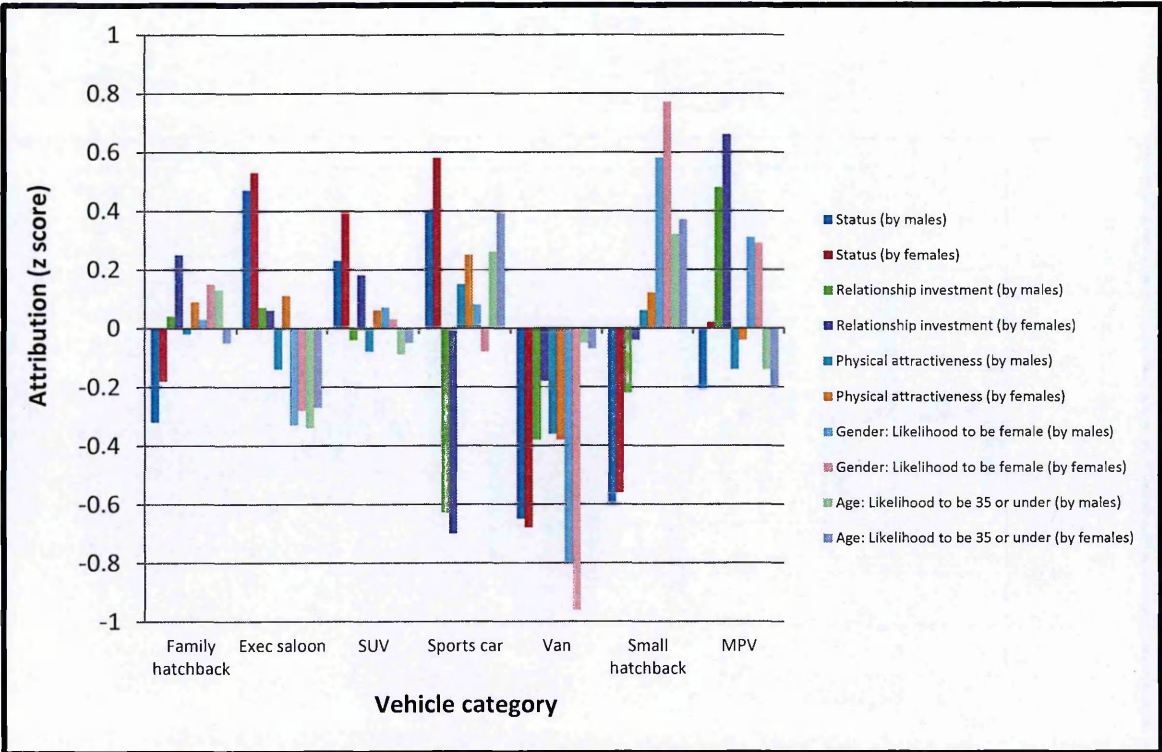


Figure 9-5. Study 7: Status, gender, age, relationship investment and physical attractiveness attributed to users of each vehicle type by male and female participants

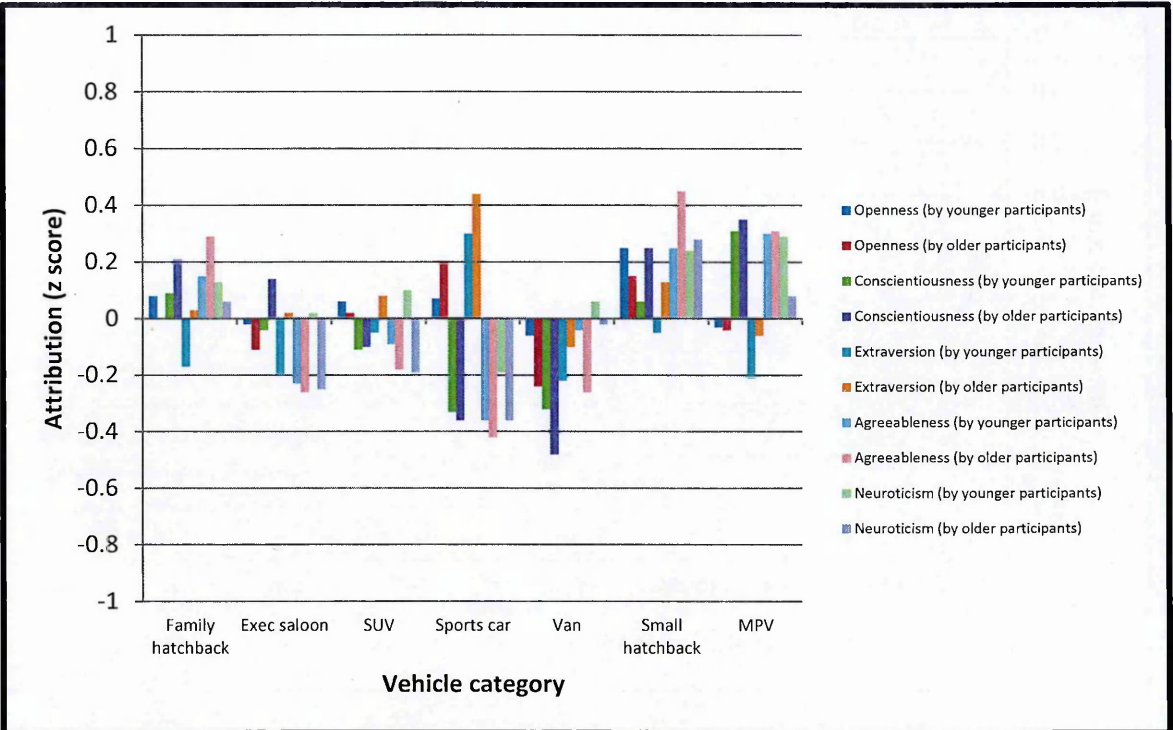


Figure 9-6. Study 7: Personality traits attributed to users of each vehicle type by younger (age 35 and under) and older (age 36 and over) participants

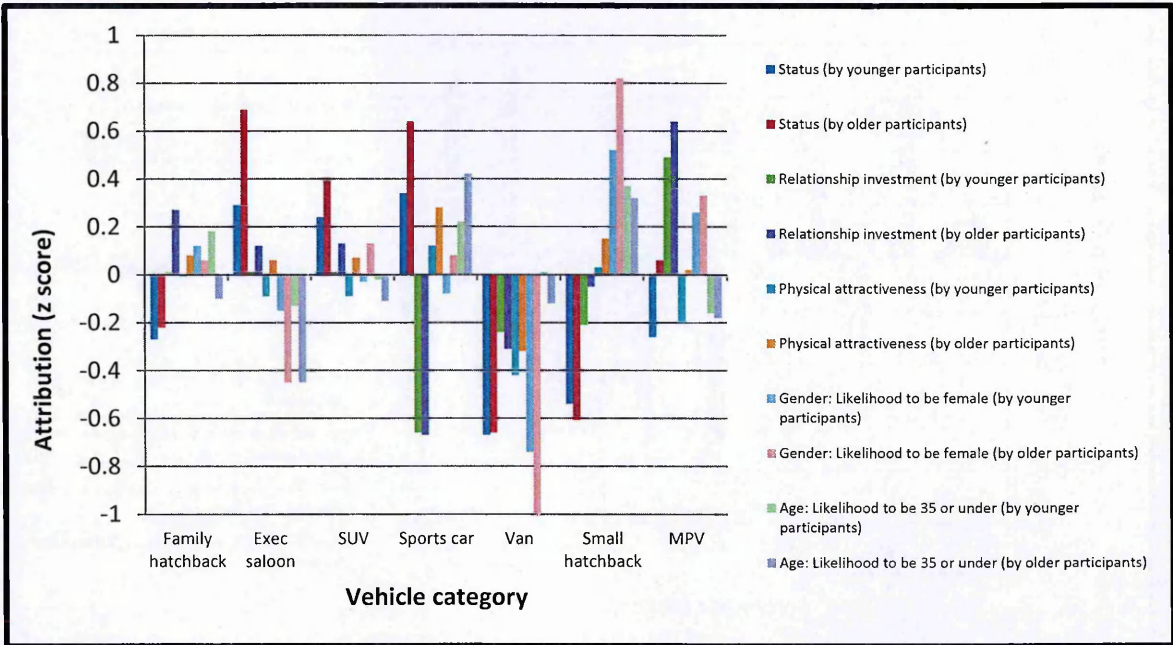


Figure 9-7. Study 7: Status, gender, age, relationship investment and physical attractiveness attributed to users of each vehicle type by younger (age 35 and under) and older (age 36 and over) participants

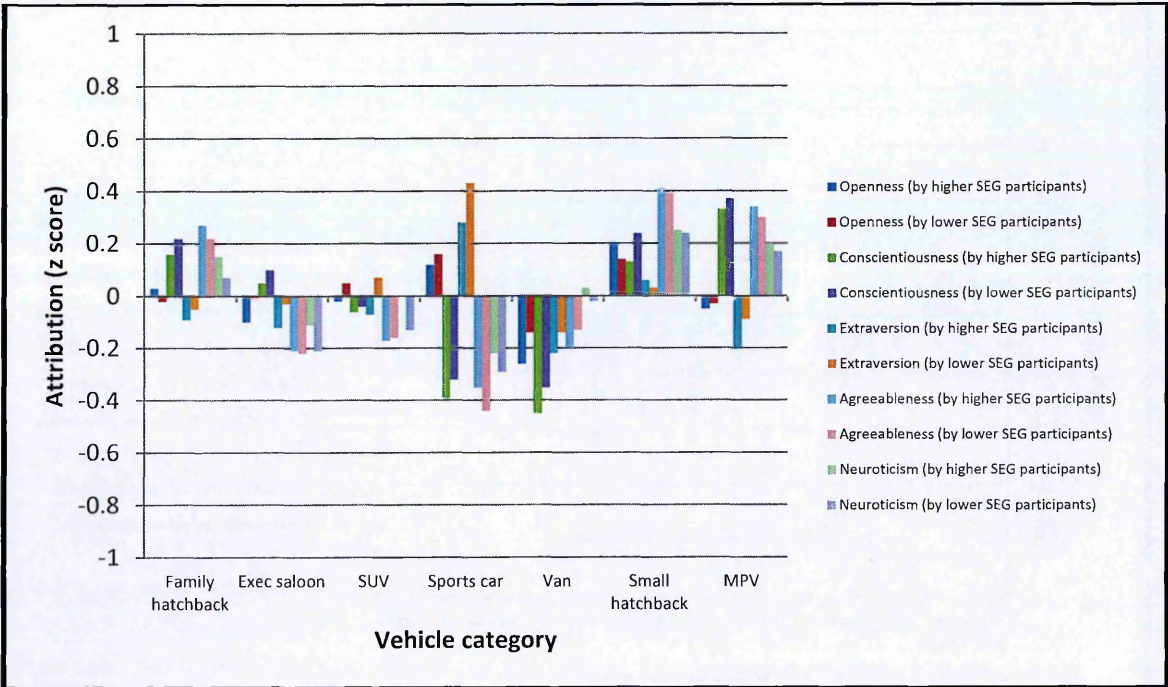


Figure 9-8. Study 7: Personality traits attributed to users of each vehicle type by higher (ABC1) and lower (C2DE) socio-economic group participants

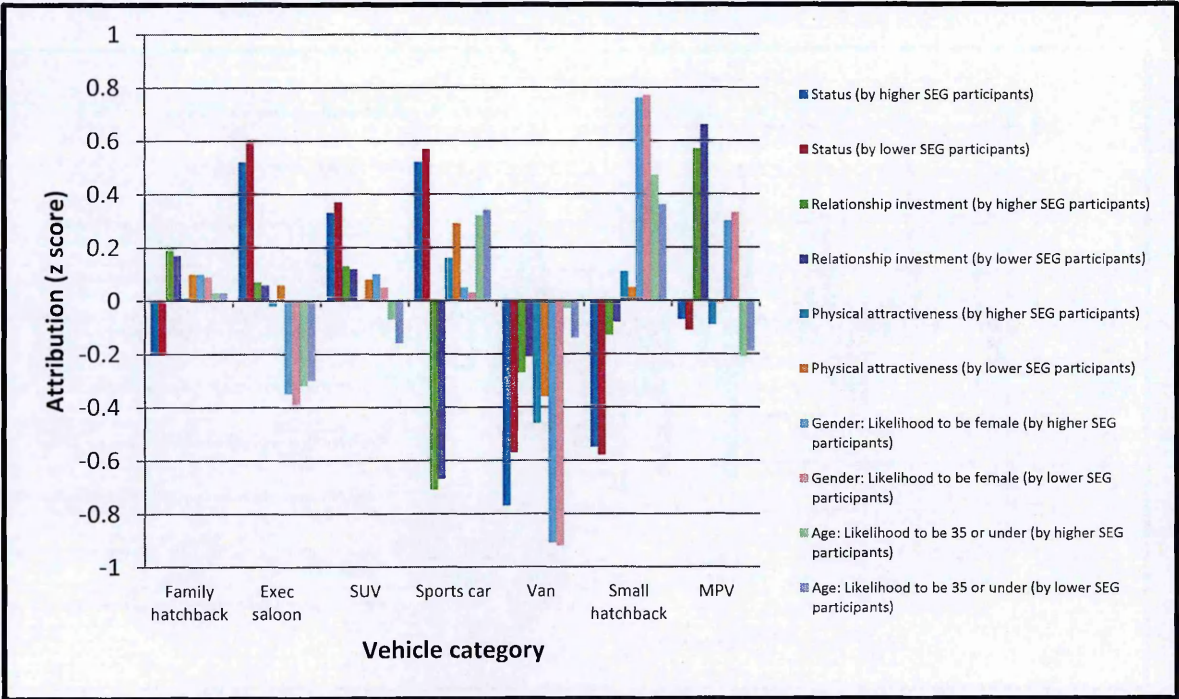


Figure 9-9. Study 7: Status, gender, age, relationship investment and physical attractiveness attributed to users of each vehicle type by higher (ABC1) and lower (C2DE) socio-economic group participants

This implies that the symbolic meanings of vehicles have value in the fulfilment of symbolic goals. A person with an existing partner might, say, have symbolic goals to signal high agreeableness, high conscientiousness and high relationship investment to that partner, as means to a higher-level goal to maintain the relationship. Using an MPV (multi-purpose vehicle) would send such signals, and so have symbolic value in relation to those goals. On the other hand, a single man in possession of a good fortune (and thus, according to Jane Austen (1813), in want of a wife, or at least, in modern societies, a short-term mate) might make use of a sports car as an effective signal to potential short-term mates - though it might also put off potential mates looking for an agreeable partner.

Previous studies have established a link between cars and their users' personalities, but without identifying specific personality trait - vehicle category associations. For instance, one theme that emerged in Fraine, Smith, Zinkiewicz, Chapman, & Sheehan (2007)'s focus group study was that cars are "a reflection of the driver's self or role", including personality characteristics and personal habits." (p.209). In other studies, particularly those exploring self-congruity, researchers have themselves assigned personality associations to particular models or brands, rather than eliciting them from participants: for instance, in the study by Grubb and Stern (1971), a panel of judges assigned "Economical, Practical, Thrifty, Dependable, Value-Conscious, Sensible, Logical and Conservative" to the brand images of Volkswagens, and "Pleasure-seeking, Sporty, Style-conscious, Youthful, Outgoing, Modern, Interested in the opposite sex, and Conforming" to the brand images of Mustangs. These assignments bear some resemblance to the symbolic meanings in my results for family hatchbacks and executive saloons on the one hand, and sports cars on the other.

Still other self-congruity studies have described measuring participant attributions using researcher-defined personality items for various car models, without however specifying the items (e.g. Heath & Scott, 1998; Sirgy, 1985). Eriksen (1996), in a self-congruity study, compared evaluations of a "stereotypical" Ford Escort driver by students from four European countries with the students' actual and ideal self-images. Again the items and item scores were not given, but the stereotypical Ford Escort driver was described as "somewhat calm, considerate, challenging, accomplished,

respectful, active, up-to-date, confident, risky, diverse, and in command". In five-factor terms, this perhaps suggests a driver who is above average in openness (up-to-date, diverse) and extraversion (active), below average in neuroticism (calm, confident) and intermediate in agreeableness (considerate, respectful, but also challenging and in command). Study 7 results for a medium family hatchback (the closest match to the Ford Escort) from younger participants did not agree particularly well with this stereotype. However there was a considerable time interval between the studies (1996 versus 2011), during which new vehicle categories have emerged (such as medium-sized SUVs and MPVs) so that the meanings of particular categories within the symbol system may have changed. Also, the younger participants in Study 7 were older than those in Eriksen's study, and all were current drivers, while Eriksen's were students and "future car purchasers".

Study 7 went much further, by measuring peoples' specific attributions of five-factor personality traits, gender, age, relationship investment and physical attractiveness to users of each major (light-duty) vehicle category. The study shows that the attribution-vignette method can characterise the symbolic meaning of a product, and enable specific, comparisons between the meanings of different products. The method should be very general in application, and be readily adaptable to any product category.

Study 8: Symbolic meaning of driving styles

Study 7 was focused on the symbolic meanings of cars as products. Study 8 shifted focus away from cars as products and onto the symbolism of a key aspect of the ways that consumers use them: the driving behaviours that people engage in with their cars, their *driving styles*. It tested the hypotheses (a) that people can make attributions of personality traits to a product user based only on knowledge of the way he/she uses a product; and (b) that the attributed personality traits are different for different usage behaviours.

As in Study 7, Study 8 also measured attributions of status, gender, age, relationship investment, and physical attractiveness that people make about the user of a car, based solely on the user's driving style, testing similar hypotheses to those concerning personality traits.

Method

Study 8 used the same method, procedure, and analyses as Study 7, with a different set of participants and different stimuli.

Participants

Participants were again UK residents from multiple locations around England, Scotland and Wales, distributed among socio-economic categories in proportion to their incidence in the general population, recruited from a market research panel. None were also participants in Studies 7 or 9. Of the 1016 participants, 518 were women (498 men); 281 were aged 35 or under (735 were 36 or over); and 568 were members of socio-economic groups A, B and C1 (448 were members of socio-economic groups C2, D or E). The mean age of the sample was 40.3 ± 12.9 years.

Stimuli

Since it was not readily possible to represent different driving styles using visual stimuli, they were instead represented by brief verbal vignettes. Each was designed to represent a driving style based on one of the eight scales in the Multi-Dimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004). Descriptions were constructed using the specific behaviours contained in the relevant items of the MDSI for each scale, as follows:

Distress Reduction style: *“Tries to relax while driving. Often does relaxation activities, such as meditating or using muscle relaxation techniques, when driving”.*

High Velocity Style: *“Gets impatient during rush hour. Often purposely tailgates other drivers. Often drives through traffic lights that have just turned red. When a traffic light turns green and the car in front doesn't get going immediately, tries to urge its driver on. In a traffic jam, thinks about ways to get through the traffic faster, and if the next lane starts to move, tries to get into it as soon as possible”.*

Angry style: *"Often, when annoyed by something another driver does on the road, flashes that driver with main-beam headlights or honks the horn. Often swears at other drivers. When another driver tries to pull in front from another lane, drives in an assertive way to prevent it"*.

Anxious style: *"On a clear motorway, usually drives at or a little below the speed limit. Generally doesn't feel in full control when driving, but feels nervous and uncomfortable. Is worried when driving in bad weather"*.

Risky style: *"Likes to take risks while driving. Enjoys the sensation of driving at the limit. Likes the thrill of flirting with risk"*.

Dissociative style: *"Often daydreams to pass the time while driving. Lost in thought while driving, fails to notice pedestrians waiting to use a Zebra crossing, or fails to notice that headlights are still on main beam. Often misjudges the speed of oncoming vehicles when overtaking. Often sets off from traffic lights in third gear. Often plans a route badly and encounters traffic. Often nearly hits something in a car park due to misjudging the space"*.

Patient style: *"When a traffic light turns green and the car in front doesn't get going, waits a while until it moves. At a junction where it is necessary to give way to traffic, simply waits patiently for the traffic to pass. Bases driving on the motto "better safe than sorry". Plans long journeys in advance"*.

Cautious style: *"Drives cautiously. Never distracted or preoccupied when driving. Never needs to slam on the brakes suddenly because the car in front has slowed down. Never gets a thrill out of breaking the law. Is always ready to react to unexpected manoeuvres by other drivers"*.

Results

Mauchly's test for sphericity was significant, indicating that variances between the differences in combinations of levels of the independent variables were unequal, so the Greenhouse-Geisser correction was applied to the degrees of freedom in the ANOVA. There was a significant item \times driving style interaction: $F(29.098, 29330.742) = 219.22, p < 0.001$, indicating that mean responses to each item varied depending on driving style. The effect size was large (partial eta squared =

0.22). Figures 9-10 and 9-11 summarise the data. The average range across driving styles was 0.83, indicating that, as with vehicle category, there was substantial variation in the symbolic meaning of the different driving styles, and that driving style did confer information about personality traits, gender, age, relationship investment, physical attractiveness and status. The traits of openness, physical attractiveness and status were more weakly signalled (i.e. had smaller ranges across the various driving styles) than the others.

There were substantial differences in attributions of all of the five-factor personality traits across the eight driving styles. For instance, the *cautious* driving style scored highly on conscientiousness; average on openness; average on extraversion; high on agreeableness; and somewhat low on neuroticism. On the other hand, the *angry* driving style scored low on conscientiousness, average on openness, average on extraversion, low on agreeableness and average on neuroticism.

Figure 9-11 also shows that participants made different attributions of gender, age, status, relationship investment and physical attractiveness in response to the different driving styles. For example, being male and being under 35 years old were attributed to the dynamic driving styles (*high velocity*, *risky* and *angry*). High relationship investment was attributed to drivers with the *patient* and *cautious* driving styles, while the opposite was attributed to drivers with dynamic styles. There was less variation in the attributions relating to physical attractiveness than other items. Highest attractiveness was attributed to the *distress reduction* and *risky* styles, and lowest to the *angry* style.

Male and female participants sometimes made somewhat different attributions, as shown in Figures 9-12 and 9-13. The item \times driving style \times participant gender interaction was significant:

$F(29.098, 29330.742) = 6.778, p < 0.001$, though the effect size was small (partial eta squared = 0.007). There appeared to be a pattern in which, if a directional attribution was made (high or low mean score on an item) then the attribution tended to be made more strongly by female participants (i.e. higher mean score for females than males if the overall mean score was high; lower mean score for females than males if the overall mean score was low). Thus, for example, low conscientiousness was attributed to drivers with the *angry* style by both male and female

participants: but the mean score attributed by females for *likes to tidy up* was lower than that attributed by males, and vice-versa for *makes rash decisions*.

The item \times driving style \times participant age interaction was also significant: $F(29.098, 29330.742) = 7.647$, $p < 0.001$, though the effect size was small (partial eta squared = 0.008). The data are shown in Figures 9-14 and 9-15. The effect was similar to that of participant gender. Across the whole data set, there appeared to be a pattern in which, if a directional attribution was made (high or low mean score on an item) then the attribution tended to be made more strongly by older participants (i.e. higher mean score for older than younger participants if the overall mean score was high; lower mean score for older than younger participants if the overall mean score was low).

Finally, there was general consistency between attributions made by higher and lower socio-economic status participants (Figures 9-16 and 9-17). The item \times driving style \times socio-economic group interaction was significant: $F(29.098, 29330.742) = 1.491$, $p < 0.001$, but the effect size was very small (partial eta squared = 0.001); there were some differences in detail in their attributions, which can be seen in the figure, which is included for completeness.

Discussion

The results of Study 8 showed that people can make attributions of personality traits to a vehicle user based on knowledge of that user's driving style, and that the personality traits attributed are different for different driving styles. Attributions can also be made in respect of the gender, age, and relationship investment of vehicle users, based on knowledge of their driving styles, and again, these attributions clearly differ by driving style. As with vehicle category, there was a broad consistency in people's attributions, although there were some modest differences in attributions by people depending on their gender and age.

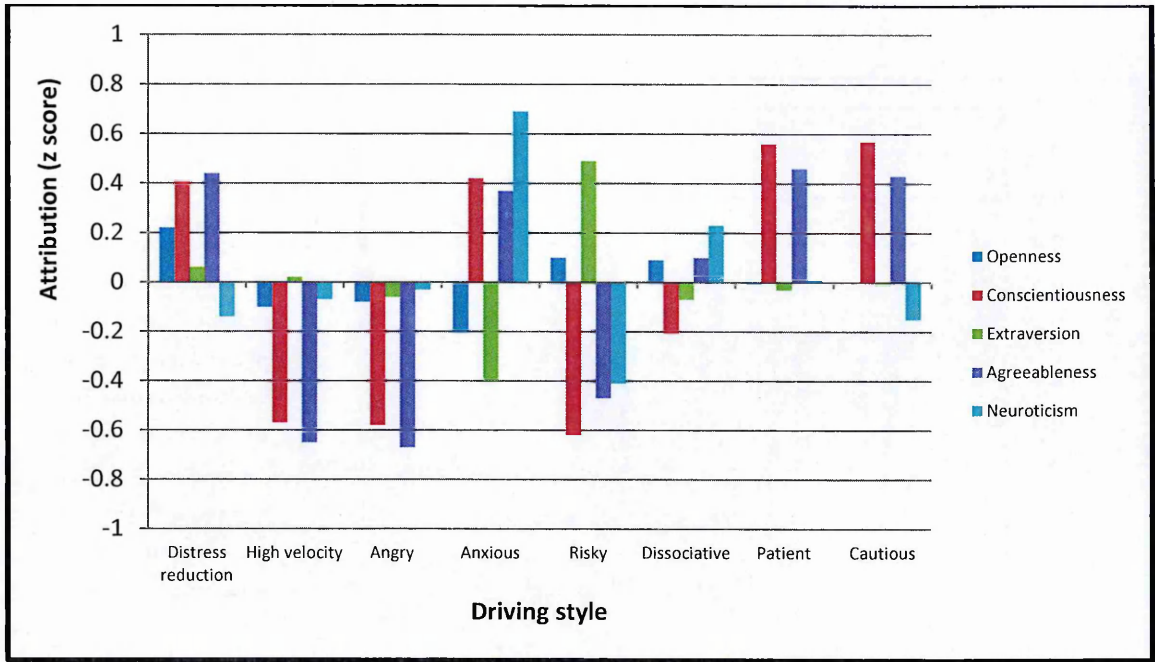


Figure 9-10. Study 8: Personality traits attributed to drivers using each MDSI driving style, by all participants

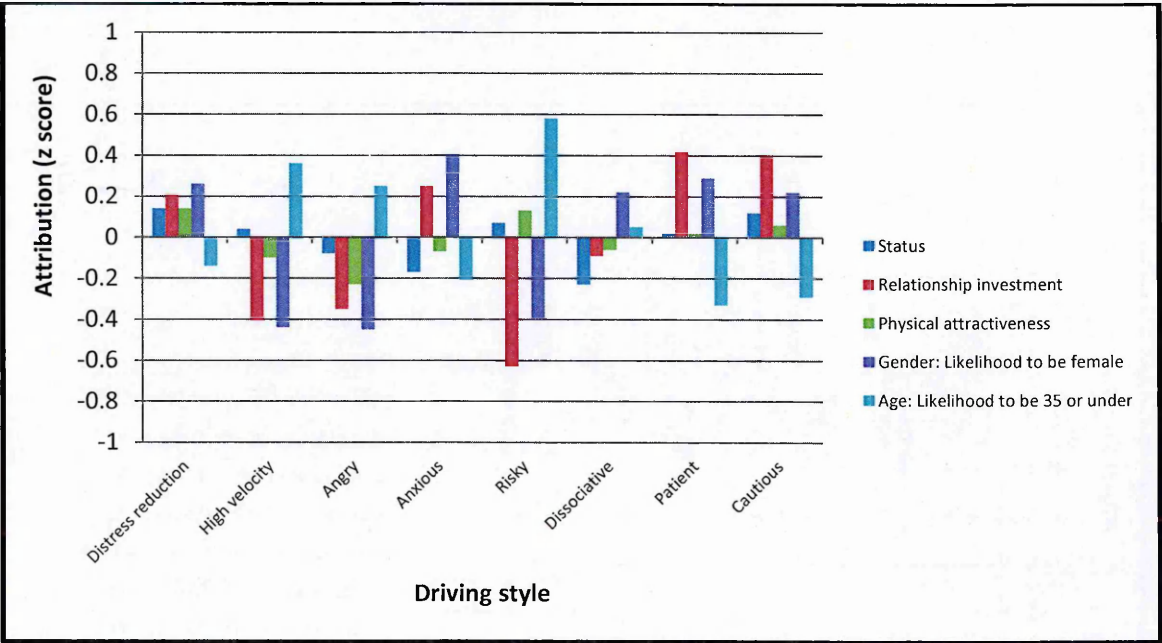


Figure 9-11. Study 8: Status, gender, age, relationship investment and physical attractiveness attributed to drivers using each MDSI driving style, by all participants

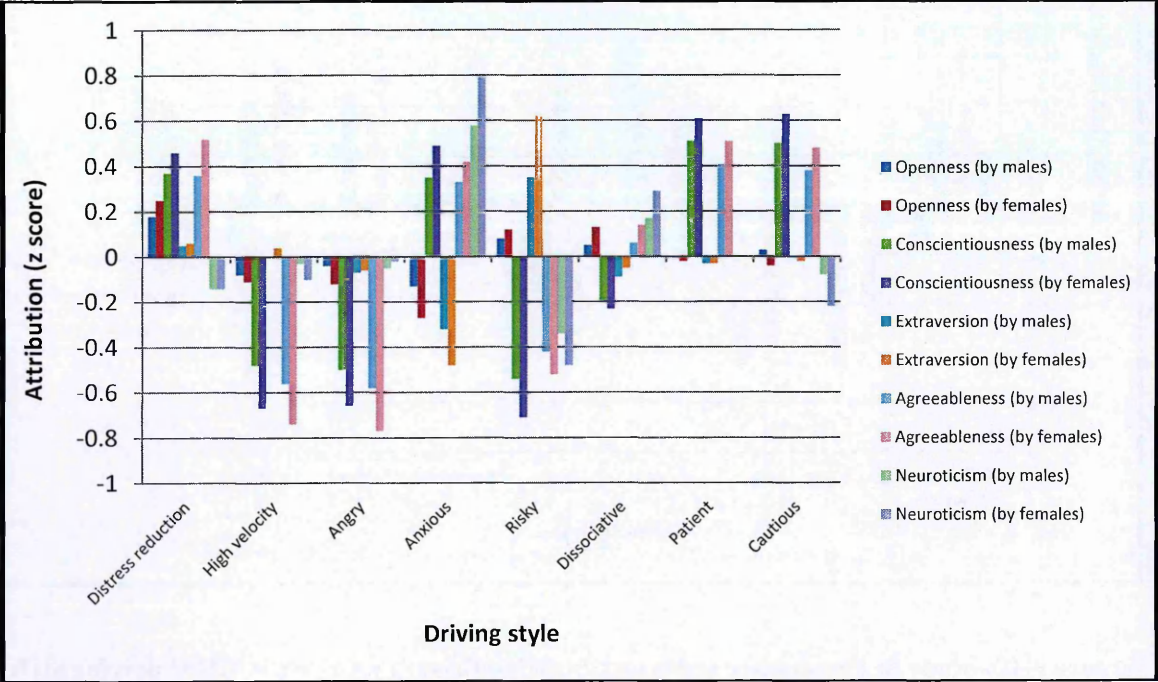


Figure 9-12. Study 8: Personality traits attributed to drivers using each MDSI driving style, by male and female participants

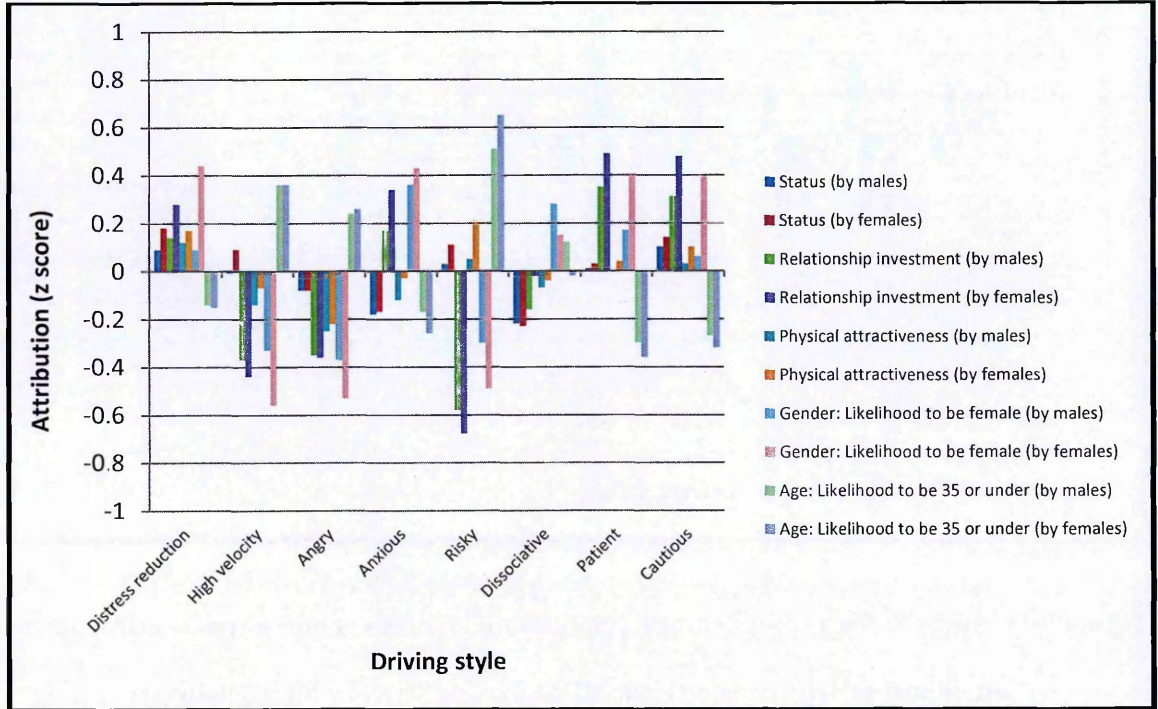


Figure 9-13. Study 8: Status, gender, age, relationship investment and physical attractiveness attributed to drivers using each MDSI driving style, by male and female participants

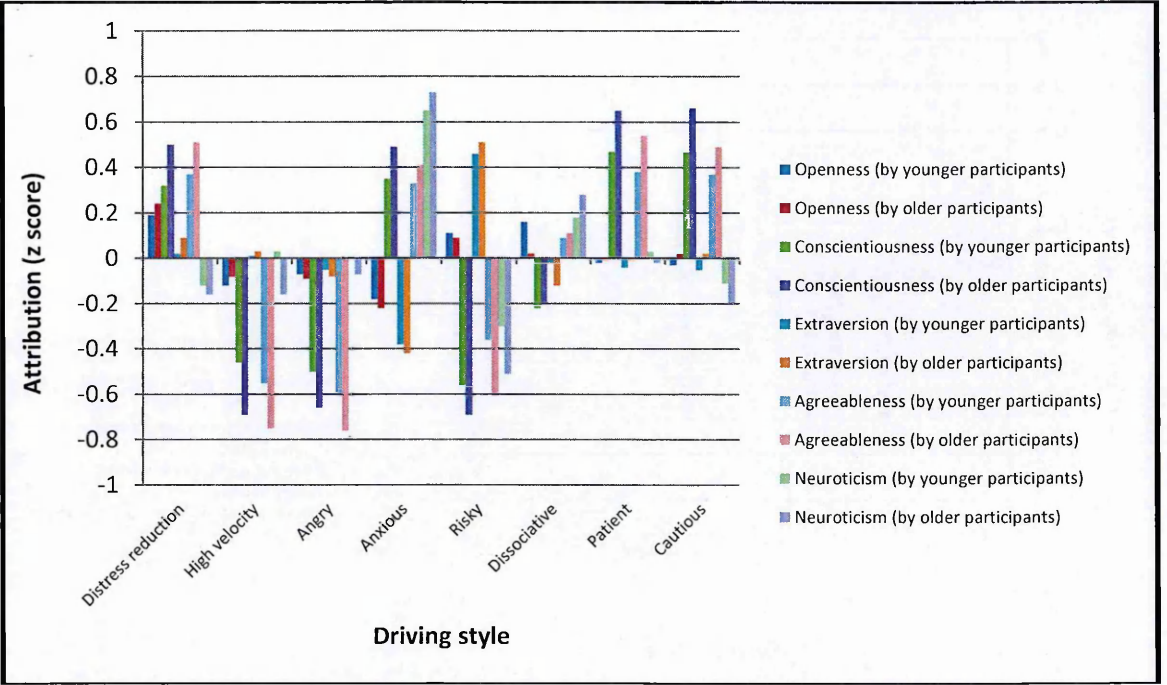


Figure 9-14. Study 8: Personality traits attributed to drivers using each MDSI driving style, by younger (age 35 and under) and older (age 36 and over) participants

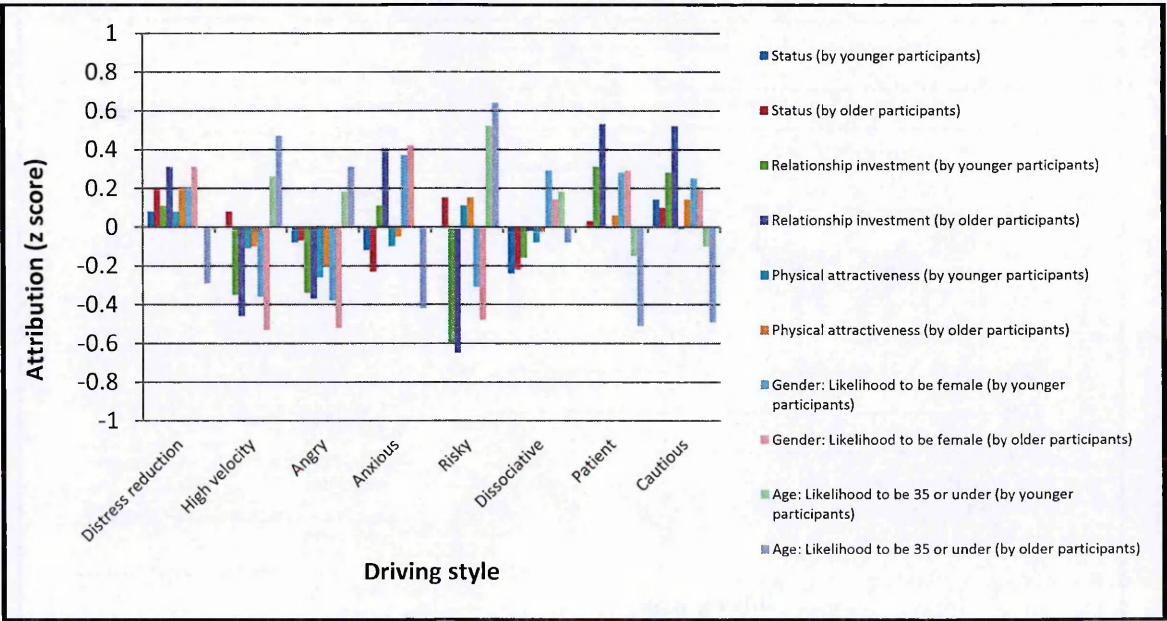


Figure 9-15. Study 8: Status, gender, age, relationship investment and physical attractiveness attributed to drivers using each MDSI driving style, by younger (age 35 and under) and older (age 36 and over)

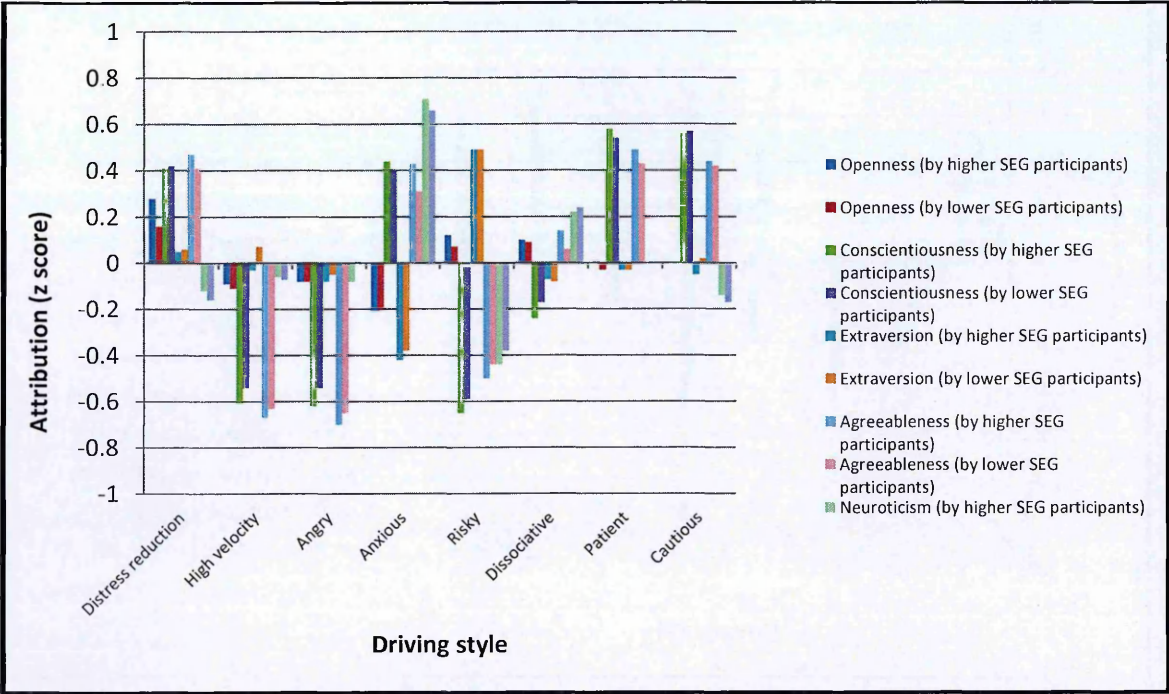


Figure 9-16. Study 8: Personality traits attributed to drivers using each MDSI driving style, by higher (ABC1) and lower (C2DE) socio-economic group participants

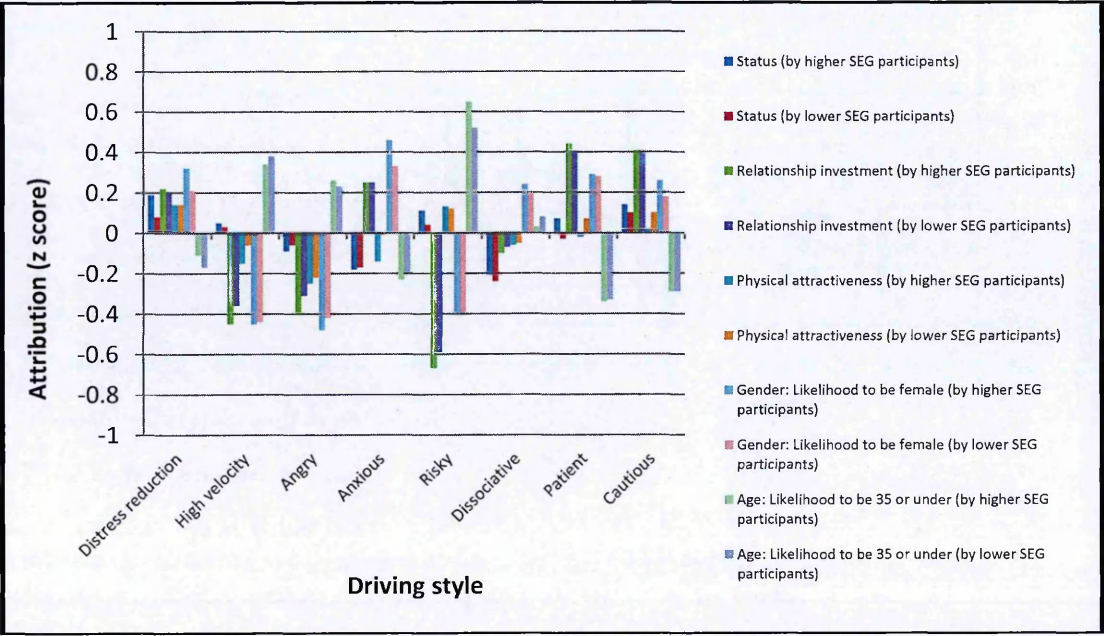


Figure 9-17. Study 8: Status, gender, age, relationship investment and physical attractiveness attributed to drivers using each MDSI driving style, by higher (ABC1) and lower (C2DE) socio-economic group participants

Thus the *way a vehicle is driven* can act as a social signal of personality, gender, age, status, and relationship investment, irrespective of the particular category of vehicle. This implies that driving style too has utility in the fulfilment of symbolic goals. So, for instance, if a young male is motivated to signal his youth, maleness and spontaneous, dominant personality to females, these results suggest that faster, riskier, more aggressive driving styles represent effective ways to do it; females will read and understand the signals. Likewise an older female might make use of *patient* or *cautious* driving styles to signal maturity, agreeableness and propensity for long term relationships.

It is interesting to note that the attributions made about personality traits based on knowledge of driving style match rather well the actual associations between personality traits and driving styles that were measured in Experiment 2. This indicates that peoples' attributions, as measured in Study 8, are soundly based: driving styles do not just signal personality, they are accurate signals of it.

In Miller's picture of sexual selection in humans, female choice is somewhat more important than male choice. Thus we might expect females to be better at reading behaviourally-based fitness indicators than males. This is consistent with the results of Study 8: females tended to make stronger attributions than males.

Study 9: The symbolic meaning of vehicle performance

Study 9 was designed to go further than Study 7 by testing the hypotheses: (a) that people can make attributions of personality traits to a product user based only on knowledge of a specific *attribute* of a product he/she is using, and (b) that the attributed personality traits are different for different attributes of that product. More specifically, Study 9 focused on the symbolic meaning of aspects of vehicle performance. As in Studies 7 and 8, Study 9 also measured attributions of status, gender, age, relationship investment and physical attractiveness to a car user, based solely on knowledge of a specific performance attribute of the user's car, testing similar hypotheses to those concerning personality traits.

Method

Study 9 used the same procedure and analyses as Studies 7 and 8, but again with a different set of participants and different stimuli.

Participants

Participants in Study 9 were also UK residents from multiple locations around England, Scotland and Wales, distributed among socio-economic categories in proportion to their incidence in the general population, recruited from a market research panel. None were also participants in Studies 7 or 8. Of the 1011 participants, 507 were women (504 men); 400 were aged 35 or under (611 were 36 or over); and 566 were members of socio-economic groups A, B and C1 (455 were members of socio-economic groups C2, D or E). The mean age of the sample was 40.2 ± 12.8 years.

Stimuli

Since it was not readily possible to represent aspects of vehicle performance using visual stimuli, they were instead represented by brief verbal descriptors. The descriptors were:

- A car that has high acceleration from standing start
- A car that is very smooth when cruising
- A car that has high power when pulling uphill
- A car that is very quiet when cruising
- A car that has high acceleration when overtaking
- A car that is very responsive to the accelerator

These corresponded to the major ways in which drivers have been found to construe vehicle performance, as identified in Study 1.

Results

Mauchly's test for sphericity was significant, indicating that variances between the differences in combinations of levels of the independent variables were unequal, so the Greenhouse-Geisser correction was applied to the degrees of freedom in the ANOVA. There was a significant item \times

performance attribute interaction: $F(25.735, 25812.456) = 119.65$, $p < 0.001$, indicating that mean responses to each item varied depending on performance attribute. The effect size was medium (partial eta squared = 0.11). Figures 9-18 and 9-19 summarise the data. The average range across performance attributes was 0.44. This indicates that, as with vehicle category, there was substantial variation in the symbolic meaning of the different performance attributes, and that performance attributes did confer information about personality traits, though not, in this case, all five traits: the range for openness was only 0.04, indicating that performance attributes did not confer an effective signal in respect of this trait. On the other hand, performance attributes appeared to confer clear signals about the traits of conscientiousness and agreeableness. Likewise, performance attributes appeared to provide clear signals of gender, age, and relationship investment, but not of physical attractiveness nor of status.

Turning to the attributions participants made about particular attributes, there was a clear distinction between attributions in respect of both of the cruising performance attributes (*very smooth when cruising* and *very quiet when cruising*) and three of the four dynamic performance attributes (*acceleration from standing start or when overtaking*; and *responsiveness to the accelerator*). Users of vehicles that were very smooth or very quiet when cruising were attributed low extraversion, high conscientiousness and agreeableness, and were seen as being in high-investment relationships, more likely to be female and more likely to be older. Quietness when cruising provided somewhat stronger signals of all of these traits than did smoothness when cruising. On the other hand, users of vehicles with high dynamic performance were attributed more or less the opposite traits in every respect: low conscientiousness and agreeableness, more likely to be male, more likely to be younger, and not in high-investment relationships. They were also attributed somewhat above-average extraversion, though this was not as strong an attribution.

The performance attribute *high power when pulling uphill* appeared not to act as a strong signal, however, in respect of any of the traits: all attributions were close to the mean.

Figures 9-20 and 9-21 show the data for Study 9 disaggregated by participant gender. Overall there was considerable consistency between attributions made by male and female participants. There were some small differences: the item \times performance attribute \times participant gender interaction was

significant, $F(25.735, 25812.456) = 2.257$, $p < 0.001$; though the effect size was small (partial eta squared = 0.002). For instance, female participants attributed higher likelihood of being female to drivers of cars with high smoothness or quietness when cruising, and higher likelihood of being male to drivers of cars with high acceleration from standing start, than did male participants.

There was also substantial consistency between attributions made by younger and older participants (Figures 9-22 and 9-23). There were some differences: the item \times performance attribute \times participant age interaction was significant, $F(25.735, 25812.456) = 5.086$, $p < 0.001$, though the effect size was again small (partial eta squared = 0.005). Older participants tended to attribute higher agreeableness, higher relationship investment and lower likelihood to be 35 or under to drivers of vehicles that were very smooth or very quiet when cruising, than did younger participants; they attributed lower agreeableness and higher likelihood of being 35 or under to drivers of vehicles with high acceleration from standing start.

However the item \times performance attribute \times participant socio-economic group interaction was not significant, $F(25.735, 25812.456) = 1.163$, $p = 0.258$, suggesting an even higher degree of consistency between attributions made by participants in higher and lower socio-economic status groups (Figures 9-24 and 9-25).

Discussion

The results showed that people can make attributions of personality traits to a vehicle user based only on knowledge of a single performance attribute of the vehicle he/she is using; and that the attributed personality traits are different for different performance attributes. Attributions can also be made in respect of the gender, age, and relationship investment of users of vehicles on the basis of the same information, and again, these attributions clearly differ by performance attribute. As with vehicle category, there was a broad consistency in people's attributions, although there were some modest differences in attributions by people depending on their gender and age.

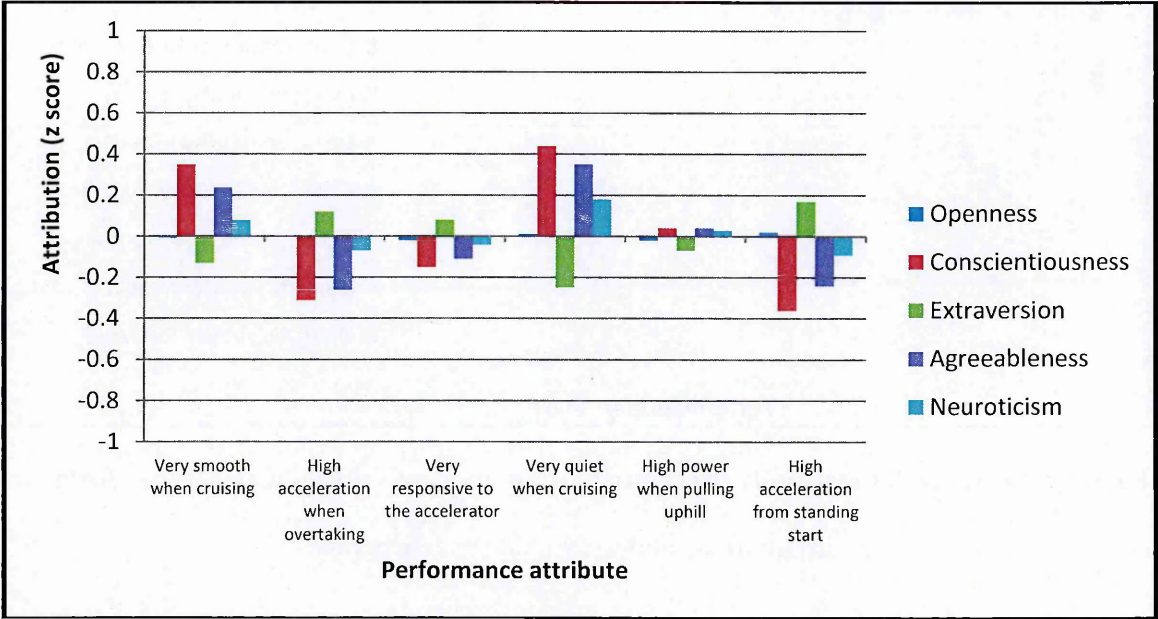


Figure 9-18. Study 9: Personality traits attributed to users of vehicles with each performance attribute, by all participants

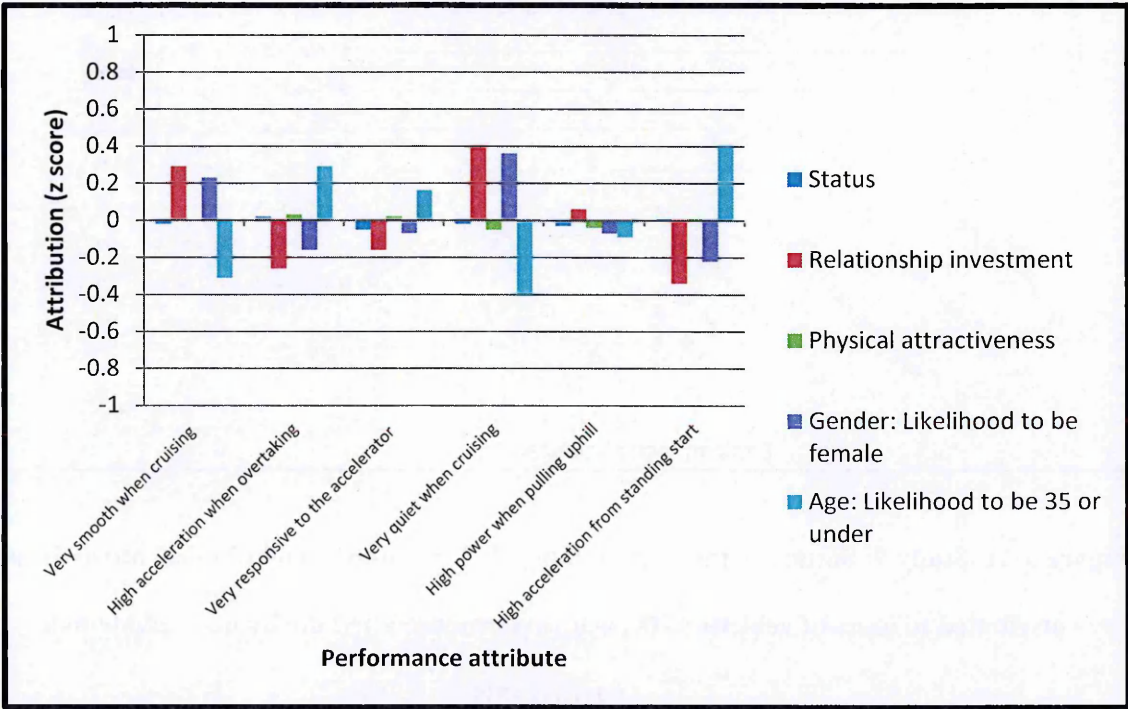


Figure 9-19. Study 9: Status, gender, age, relationship investment and physical attractiveness attributed to users of vehicles with each performance attribute, by all participants

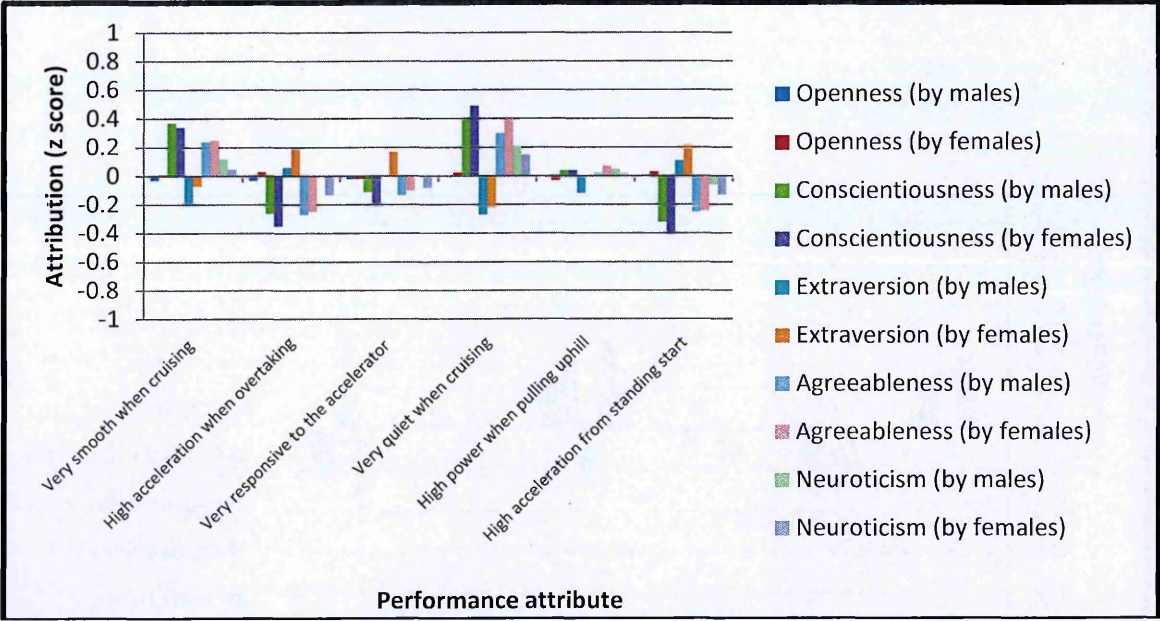


Figure 9-20. Study 9: Personality traits attributed to users of vehicles with each performance attribute by male and female participants

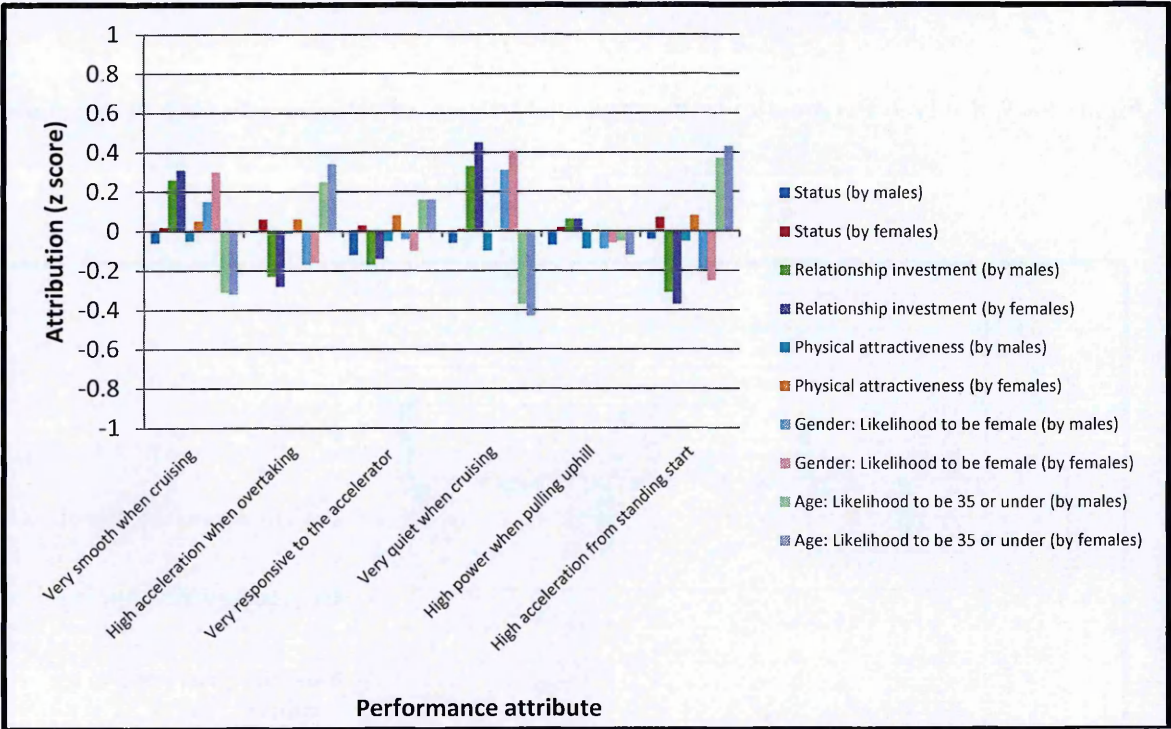


Figure 9-21. Study 9: Status, gender, age, relationship investment and physical attractiveness attributed to users of vehicles with each performance attribute by male and female participants

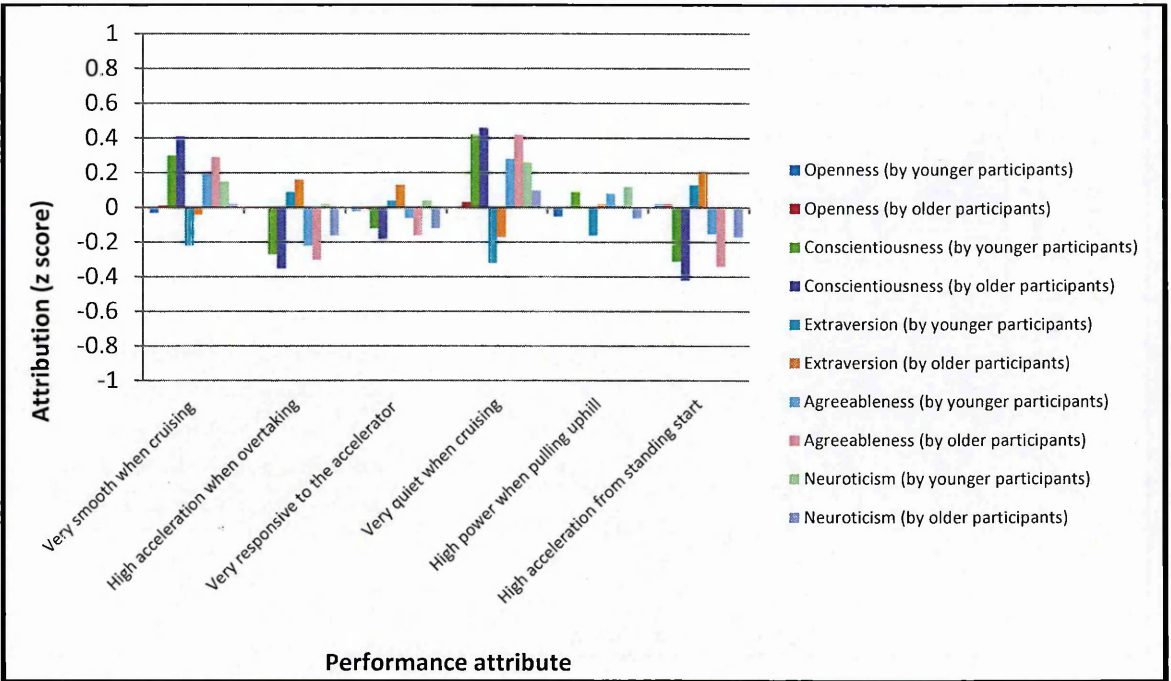


Figure 9-22. Study 9: Personality traits attributed to users of vehicles with each performance attribute by younger (age 35 and under) and older (age 36 and over) participants

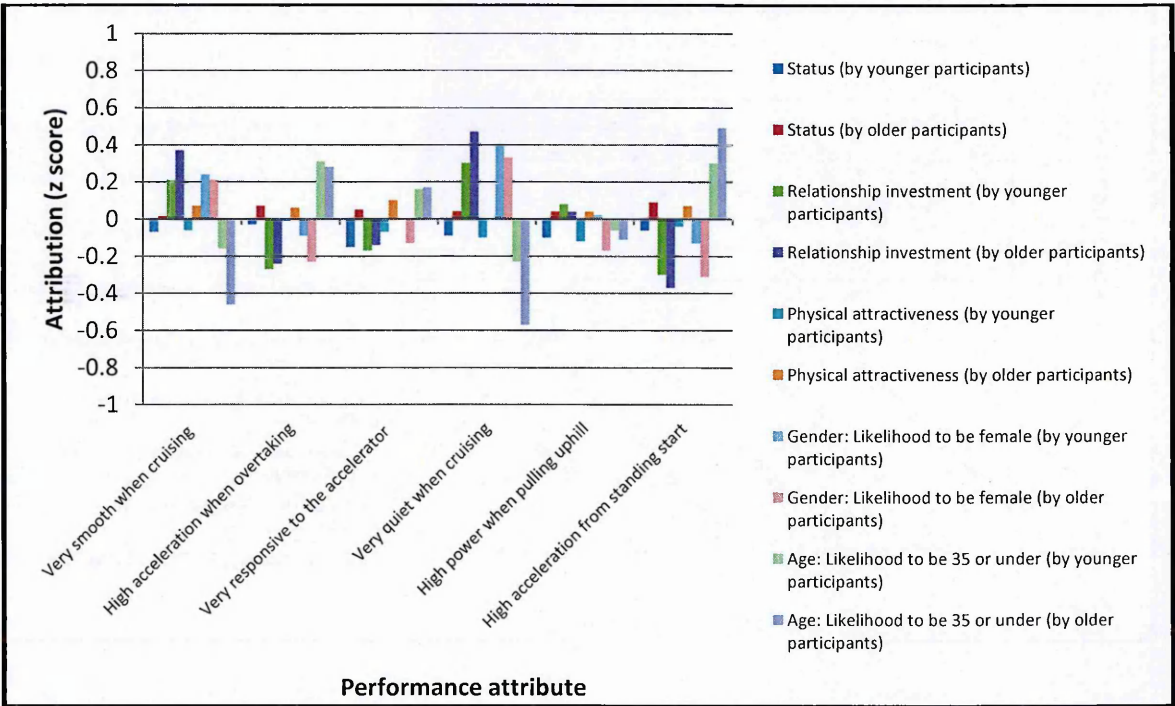


Figure 9-23. Study 9: Status, gender, age, relationship investment and physical attractiveness attributed to users of vehicles with each performance attribute by younger (age 35 and under) and older (age 36 and over) participants

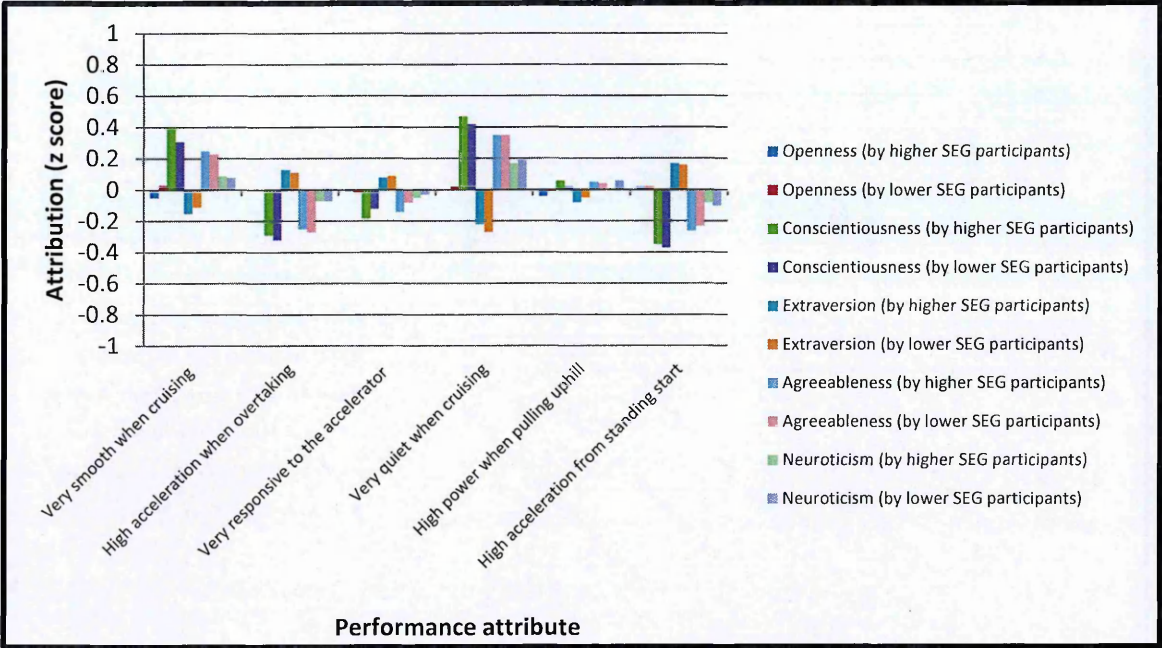


Figure 9-24. Study 9: Personality traits attributed to users of vehicles with each performance attribute by higher (ABC1) and lower (C2DE) socio-economic group participants

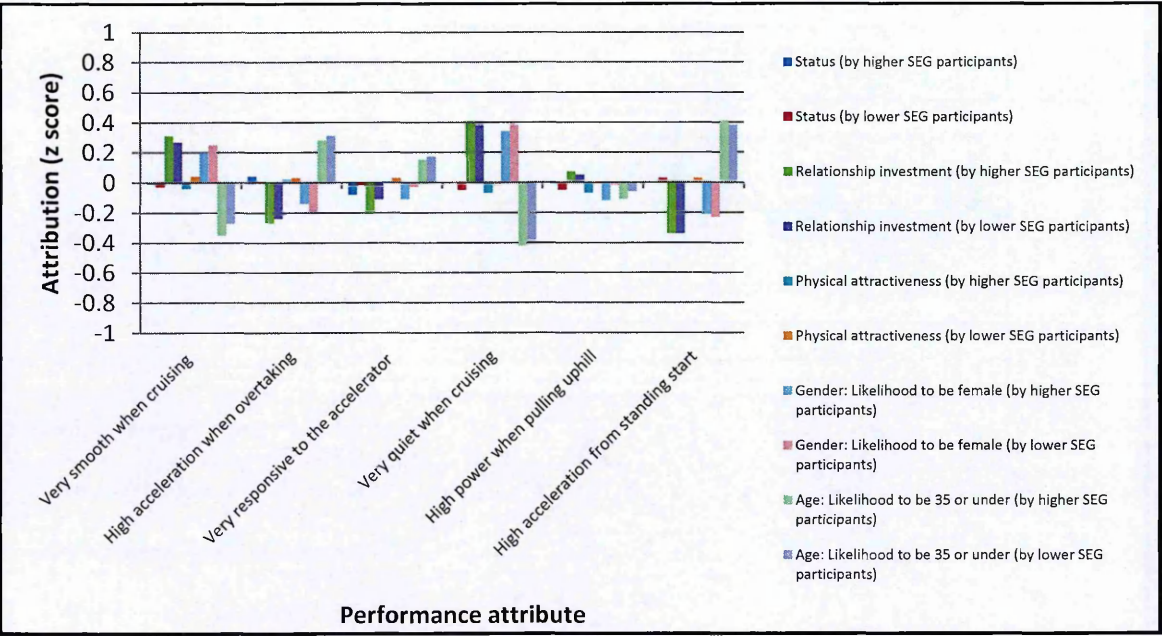


Figure 9-25. Study 9: Status, gender, age, relationship investment and physical attractiveness attributed to users of vehicles with each performance attribute by higher (ABC1) and lower (C2DE) socio-economic group

It follows that the *performance* of a vehicle can act as a social symbol of personality, gender, age, and relationship investment, irrespective of the particular category of vehicle. This implies that vehicle performance has value for the fulfilment of symbolic goals. A person with symbolic goals to signal high agreeableness, high conscientiousness and high relationship investment can do so by driving a vehicle which is smooth and quiet when cruising. On the other hand, a person with symbolic goals to signal masculinity, youth, spontaneity (low conscientiousness) and ambition, social dominance, etc. (low agreeableness) can do so by driving a vehicle which has high dynamic performance. High acceleration from standing start appears to provide the strongest signal of the latter: it is therefore not surprising that racing other drivers “off the line” at traffic lights is such a common behaviour for young male drivers.

Could high performance, as an attribute of an *inexpensive* car (say, an older, used car) still act as a *costly* signal (i.e. one that is difficult to fake, because it requires the signaller to invest something in its production)? The answer is yes, provided we understand “costly” in terms of having adverse consequences for the pursuit of other personal goals. Having a high-performance vehicle facilitates symbolic goals to signal certain personality traits, but imposes costs in the sense that making use of it potentially compromises personal safety (i.e. survival-oriented, rather than reproduction-oriented goals). There is compelling evidence, for example, that young adults are willing to engage in behaviours that involve risk of physical harm, if they perceive that this will increase their chances in the pursuit of romantic opportunities (Siegel, 2011).

General discussion

Studies 7, 8, and 9 provide the first quantitative picture of the symbolic meanings of cars, driving and vehicle performance. The results show that all of these have a rich set of meanings, widely understood and shared by members of the society in which they are used. They thus act as a symbol system, a symbolic language that users can draw on in the pursuit of their symbolic goals.

Study 7 shows that the attribution-vignette method can characterise the symbolic meaning of a product, and enable specific comparisons between the meanings of different products. The method

should be very general in application, and be readily adaptable to any product category. Further, Study 8 shows that it can be used to characterize the symbolic meaning not just of a product itself, but of the *way that a product is used*; and Study 9 shows that it can characterise the symbolic meaning of a *specific attribute of a product*. This makes the method even more powerful and more general in its application.

Consistency of signals

There was a great deal of consistency in the findings. Five-factor personality traits such as low agreeableness and low conscientiousness, together with other mating-salient traits such as masculinity, youth, and low relationship investment, are signalled by exemplars, in each of the three symbol categories, that appear very consistent with each other: categories of cars (e.g. sports car), dynamic performance attributes (e.g. acceleration from standing start), and more dynamic driving styles (*risky, angry, high velocity*). At the same time, other five-factor personality traits such as high agreeableness and high conscientiousness, together with other mating-salient traits such as being older, and high relationship investment, are signalled by equally consistent, but different exemplars: MPVs (people carriers), cars that are very quiet when cruising, and *patient* and *cautious* driving styles. There was also quite considerable consistency of meaning between social categories: meanings were similar for both male and female participants, older and younger participants, and participants who were members of higher and lower socio-economic groups.

Consumer products signal the personality traits of their users

The key to being able to quantify and compare symbolic meanings in this way is the theoretical perspective that what is symbolised by consumer goods and the ways they are used is not information about the goods themselves, but information about the people who use them. Personality is one of the most useful things we can know about another person: it allows us to make predictions about their likely behaviour in future contexts. As discussed in the previous chapter, Miller (2009) theorised that personality traits act as reproductive fitness indicators – they provide information about the value of another person as a potential (or current) mate. Thus people are strongly motivated to discern the personality traits of those with whom they interact; and to signal

their own personality traits to others. Anything which can act as a signal of personality traits, particularly a costly signal (one that requires investment of resources, so is costly to make and difficult to fake cheaply), therefore has value. Miller argues that a wide range of behaviours (Miller, 2000) and consumer products (Miller, 2009) provide such costly signals. Studies 7, 8 and 9 support this argument with direct evidence that consumer products, and the ways they are used, do indeed act as signals of personality traits.

From this perspective, information about the user's five-factor personality traits is the ultimate symbolic meaning of any consumer product. Of course, products and their uses can have a wealth of other meanings, as shown by the extensive literature, both social psychological (Dittmar, 1992; Dittmar & Brown, 2008) and anthropological or sociological (e.g. Miller, 2010; Shove, 2003; Shove, Watson, Hand, & Ingram, 2007; Trentmann, 2006). I interpret these additional meanings as hierarchically subordinate to meanings in terms of the personalities of users – they represent the many nuanced *ways* in which personality traits can be signalled.

It would be straightforward to extend the scope of the present methodology to quantify and compare any such additional meanings, by framing them in terms of particular information about the typical user of the product in question.

Potential ways to extend the method

In these studies, the norms used to transform the raw data into z-scores were derived from the overall means and standard deviations of the total responses for each attribution item within each study. Thus the results for any one vehicle category (Study 7) were expressed in relation to the distribution of meanings across all vehicle classes, etc. The reason for this approach was that, in the attribution-vignette method, we are seeking to identify the symbolic meaning of a product *relative to the meanings of other symbols in the symbol system of which it is part*. Thus the appropriate comparison group is the distribution of traits signalled by the symbol system (rather than the distribution of traits in a population of people). This approach is justified in studies such as these, where data on participants' attributions are collected for a comprehensive range of symbols in the relevant symbol system (e.g. vehicle types or driving styles).

However it is easy to envisage situations where it would be desirable to characterise the symbolic meaning of a product, product attribute or usage behaviour using this methodology, without the need to measure the meanings of a comprehensive range of other products or behaviours against which to compare it. To do that, we would need a set of general norms that could be applied to any product or behaviour. One option might be to carry out an extensive study of attributions towards users of a very wide range of consumer goods, e.g. clothes, foodstuffs, cars, phones, refrigerators, watches, books, films, furniture; and to do so with participants from a variety of cultures where meanings might differ. The distributions of responses would then provide comprehensively applicable norms. However that approach would require a major programme of research, and there might be changes in symbolic meanings during the elapsed time taken to collect the data.

A simpler approach might be to relate observer attributions about the traits of the user of a product directly to the distributions of those traits in the population. For personality traits, that would require the experimenter having access to representative norm group data for an observer-rating personality inventory (such as exists for the observer rating version of NEO-PI-3). Alternatively, norms could be generated for an observer rating version of a medium-length personality inventory, such as the 60-item NEO-FFI (McCrae & Costa, 2004), or short inventories such as the 10-item TIPI (Gosling, Rentfrow, & Swann, 2003), BFI-10 (Rammstedt & John, 2007) or Newcastle Personality Asessor (Nettle, 2007). Norms would also need to be generated in the same way (via observer rating of a population-representative sample) for non-personality traits such as age, gender, relationship investment, physical attractiveness and status, or for any other information about the user that was considered salient for a particular product or usage behaviour.

Symbolic meanings of electric vehicles

One notable omission from the categories of vehicles in Study 7 was electric vehicles. There was good reason for their omission: most people in the general population of the UK at the time of the study had no direct experience of electric vehicles. Assessment of consumers' responses to "really new" product categories can be methodologically challenging (Hoeffler, 2003). Construal Level Theory (Liberman, Trope, & Stephan, 2007; Trope & Liberman, 2003) proposes that "psychological distance" affects the level of abstraction with which a product is construed. An

object is psychologically distant when it is detached from a person's direct experience: the more psychologically distant an object, the more it is construed in high-level, abstract terms, rather than low-level, concrete terms. This suggests that research with participants who have not experienced EVs may be subject to large uncertainties (Graham-Rowe et al., 2012). Accordingly, EVs were not included as a category in Study 7. However I shall return to the symbolic meaning of EVs in Chapter Eleven, where the attribution-vignette method will be used again, with a sample of consumer drivers after they have had direct experience of using an electric vehicle themselves.

Acknowledgments

Coding of the questionnaires, participant recruitment and data collection for studies 7, 8, and 9 was carried out by the research agency Jigsaw Research. The author designed the studies, the procedures, and the questionnaires, and conducted all the analyses.

Material on Study 8 has been published in an edited collection (Skippon et al., 2012).

Chapter Ten. Implicit associations between product concepts and their symbolic meanings

In the previous chapter I measured the explicit symbolic meanings of categories of products (vehicles), their attributes, and the ways people use them (driving styles), using an explicit attribution-vignette method based on Miller's (2009) costly signalling theory. However an explicit measure will not necessarily capture the full symbolic meaning associated with a consumer product. First, a participant may give a strategic or socially desirable response that reflects the participant's communicative goal(s) in giving the response: a demand-characteristic problem (Robson, 2002). Second, a participant may have implicit associations in memory between the consumer product and its symbolic meaning, of which he/she is not consciously aware. Third, it may be that participants' attributions do not represent associations between the products and personality or status meanings in long-term memory, but rather are constructed in-the-moment when the survey question is answered. For these reasons, additional methods are needed that supplement the explicit measurement with implicit measures of the association between the consumer product and its symbolic meaning.

Implicit measures of attitudes can potentially be adapted for this purpose. Attitude researchers also face the issues outlined in the last paragraph, and have developed various alternative "implicit" methods (Musch & Klauer, 2003; Wittenbrink & Schwarz, 2007). "Implicit" here means that the participant's responses are produced through processes that are "uncontrolled, unintentional, goal independent, purely stimulus driven, autonomous, unconscious, efficient, or fast" (De Houwer & Moors, 2007, pp.188-189). There are two major classes of implicit measures in attitude research (for a review of these, and other less frequently used methods, see Wittenbrink & Schwarz, 2007). These are the Implicit Association Test and its variants, and priming methods.

The principle application of the Implicit Association Test (IAT) (Greenwald, McGhee, & Schwartz, 1998; Lane, Banaji, Nosek, & Greenwald, 2007) is to measure the degree of association between a pair of target concepts, and a pair of attributes that the target concepts might or might not have (in the original study by Greenwald et al. the target concepts were Flower and Insect, and

the attributes were Good and Bad). One concept and one attribute are paired together at one side of the computer screen and the others are paired on the opposite side. Items appear in the centre of the screen, and participants must categorise them as belonging to the pair of categories on the left or right of the screen. Responses are expected to be faster when the concept-attribute pairs are associated than when they are not associated. In principle, the IAT might be adapted to measure the strength of implicit association between an aspect of vehicle performance (concept) and a personality trait (attribute).

Priming, in its general sense, is a change in performance on a perceptual or cognitive task, relative to an appropriate baseline, produced by context or prior experience. Priming as a means to measure implicit attitudes is based on the concept that the speed with which a participant can make a judgment can be affected if the judgment task is preceded ("primed") by exposure to an attitude object which facilitates or inhibits processing of the judgment (Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Gaertner & McLaughlin, 1983; Greenwald, Klinger, & Liu, 1989; Meyer & Schvaneveldt, 1971; Meyer, Schvaneveldt, & Ruddy, 1975; Neely, 1976). Participants are exposed first to a "prime" (typically a word, or image), then to a "target" (again, typically a word or image) about which they must make a judgment (for instance, whether the target is a real word, or whether it is good or bad). Participants tend to be faster at making judgments when the prime is associated with the target in some way, for instance semantically. This effect is frequently explained in terms of spreading activation models (McNamara, 2005; Wittenbrink, 2007), in which activation of the prime in long-term memory causes activation to spread to related concepts via links in a semantic network in memory. As a result of being pre-activated in this way, related targets are more readily recognized and can be responded to faster (Neely, 1977; Posner & Snyder, 1975; Wittenbrink, 2007; for competing models in semantic priming, see McNamara, 2005; for competing models in relation to word recognition, see Kinoshita & Lupker, 2003). In Interactive Activation and Competition models (Davis, 2003; McClelland & Rumelhart, 1981) activation does not simply spread between nodes in the network: nodes transmit both excitation and inhibition to related nodes, so there is a competition for activation.

Two broad paradigms of priming experiment have emerged in implicit attitude research: evaluative priming (also referred to as affective priming) and concept priming. In evaluative priming (Banse, 2003; Fazio et al., 1986; Klauer & Musch, 2003), primes are paired with target words that have evaluative valence (such as awful, repulsive, frightening, pleasant, nice, friendly). The judgment task is to decide if the target word implies *good*, or *bad*. If the participant has a positive attitude to the attitude object (the prime), then it should be easier (and quicker) to give a response “good” than to give a response “bad”, because the prime has pre-activated the valence representation “good”. Evaluative priming can thus be used to assess implicit evaluations of attitude objects.

Concept priming, on the other hand, assesses conceptual associations between prime and target. Targets are used that vary in their degree of possible association with the prime. They are typically presented in the context of a lexical decision task (is the target a word?). If the target is associated with the prime, then its representation should have been to some extent pre-activated by the prime, making the decision task easier and quicker (Wittenbrink, 2007). In principle, concept priming might be adapted to measure the strength of implicit association between an aspect of vehicle performance (prime) and a personality trait (target).

De Houwer (2003) developed a taxonomy of implicit methods based on structural features. The taxonomy distinguished two types of compatibility manipulation. In response compatibility, the response characteristics of the attitude object are compatible or not with the response requirements of the task. The IAT involves response compatibility manipulation: if, say, Flower is associated with Good and Insect with Bad, then responses are compatible when Flower and Good are on the same side of the screen, and incompatible when they are not. De Houwer distinguished this from stimulus compatibility, in which the task requirement is the same, but the compatibility of stimuli is manipulated. For instance, in concept priming, the response required is the same regardless of the prime (e.g. indicate whether or not the target is a word), but the prime may or may not be compatible (i.e. associated with) the target. The two main priming paradigms, while superficially similar, differ with respect to De Houwer’s taxonomy. Evaluative (affective) priming is based on manipulating response compatibility, and so is grouped with the IAT, rather than with concept priming, which is based on stimulus compatibility.

The IAT is regarded as easier to implement, as generally producing larger effect sizes and as having greater reliability compared with priming methods (Lane et al., 2007; Wittenbrink, 2007). On the other hand, concept priming has several advantages: firstly, there is no need to define constructs in terms of comparison pairs (such as good-bad; Black-White; Bush-Gore); priming methods can measure single associations. Secondly, in the IAT, participants are invariably consciously aware of the categories, and frequently guess the purpose of the experiment, even if in principle they cannot control the speed of their responses. This means that it is not possible to say unequivocally that an IAT result arises from non-conscious processes. In concept priming, it is possible to present the primes subliminally (so that the participant is unaware of their having being presented) so that it is clearer that conscious processing has been eliminated. Finally, while spreading activation and other models offer a theoretical understanding of the mental processes involved in priming (McNamara, 2005), there is some uncertainty and debate about the processes that underlie the IAT (Lane et al., 2007).

Experiments 10, 11 and 12 therefore aimed at identifying implicit associations between products and personality or status meanings, using a concept priming paradigm. The basis of the paradigm was that, if the representation of a product in memory is associated with certain personality traits or status information, then activation of that representation would cause activation of representations of the relevant trait or status information. While those representations remained activated, then performance on subsequent tasks involving personality or status judgment would be influenced by the pre-existing activation. In the experiments, participants viewed a series of faces and were asked to judge their personalities and status. Prior to each face, participants were presented with a prime image of a product, or a control image. The effects of the primes on the attributions of personality or status to the faces were measured.

Experiment 10

The paradigm was piloted in Experiment 10 using prime images of two of the vehicle types from Study 7: *small hatchback* and *sports car*, and an image of a light bulb as a control. Prime type was

the within-participants variable. Dependent variables were the frequency of yes/no judgments on a range of personality and status items across a set of face images preceded by the three prime types.

In principle, activation should only spread to representations of personality traits and status if an integrated percept of the prime image has been activated (since it is that percept, not lower-level features of the image, that is associatively related to personality traits and status). Visual processing begins with detection of simple features, such as line orientations in visual area V1 of the brain (Bullier, 2001; Lamme & Roelfsema, 2000). The feed-forward sweep of activation passes information from lower-level areas, V1 and V2, to higher level areas that process more complex aspects such as movement (Bullier, 2001), and groups features into constellations. However the formation of coherent percepts, where features are combined into objects, requires the operation of recurrent processing, involving widespread interaction between visual areas and feedback from higher to lower level visual areas, and this process appears to take in the order of 100ms (Lamme & Roelfsema, 2000; Lamme, Zipser, & Spekreijse, 2002). It follows that the prime image in this experimental paradigm should not activate personality trait or status associations if it is only visible for a very short duration (such that only feedforward processes have occurred). These associations should be activated, however, if the prime duration is sufficient for feedback and recurrent processing to have occurred. To test this, prime duration was varied as an additional, between-participants independent variable.

Method

Task

Participants were asked to carry out a “judging personality” task. A personality item (expressed as a statement about behaviour) or a statement about status was presented on a computer screen, followed by a series of faces. On presentation of each face, participants answered “yes” or “no” (using the “n” or “m” keys on the keyboard) based on whether they judged the behaviour to be characteristic of the person whose face they were viewing.

Immediately prior to the presentation of each face, a prime image was presented: either a *small hatchback* car, a *sports-car*, or a *light-bulb* control (Figure 10-1). The prime image was presented

either for 10ms (*short prime condition*) or 80ms (*long prime condition*). Half of the participants experienced the short prime condition (for all primes) and half the long prime condition (also for all primes). Prime images were preceded and followed by a mask (Figure 10-2) whose area was larger than the prime and face images. Masks were presented for 200ms, irrespective of the prime duration. Both forward and backward masks act to suppress conscious awareness of primes (Breitmeyer, 2007; Breitmeyer & Ögmen, 2006) by interfering with integration of feedback from higher to lower level areas of the brain (Lamme et al., 2002). In the case of backward masking, by the time high-level feedback signals reach lower levels, information at these levels is not about the prime stimulus, but about the mask, so integration is disrupted (Enns & Di Lollo, 2000); and vice-versa for forward masking. Figure 10-3 shows the complete prime-target sequence.

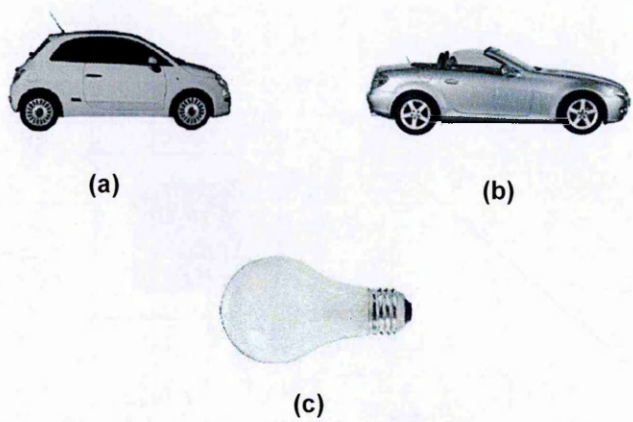


Figure 10-1. Prime images: (a) small hatchback car; (b) sports-car; (c) light-bulb (control)

The experiment was divided into twelve blocks, one for each personality/status item. Sixty different faces were presented in each block, twenty preceded by each prime image. The order of presentation of both faces and prime images was randomized. The sixty faces were drawn from a computer generated set, thirty male and thirty female, all monochrome and similar but not identical in facial expression. The images were generated using the Genhead 1.2 package from Genemation Inc. Figure 10-4 shows a selection of the faces. The order of the twelve blocks (personality and status items) was randomized between participants. Each participant completed 720 (12×60) face-personality/status judgments, of which one-third were preceded by the *light-bulb* control prime,

one-third by the *sports-car* experimental prime, and one-third by the *small hatchback* experimental prime.

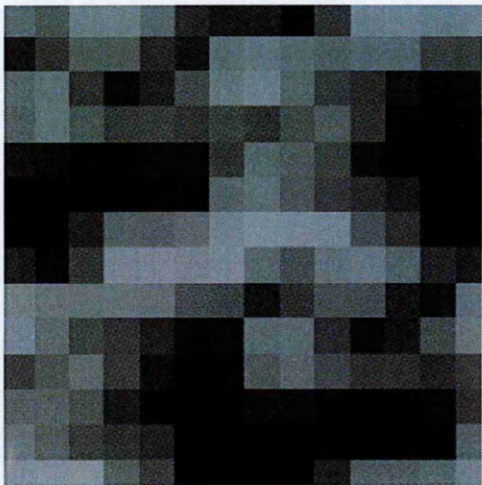


Figure 10-2. Mask image (one of four used in random order)

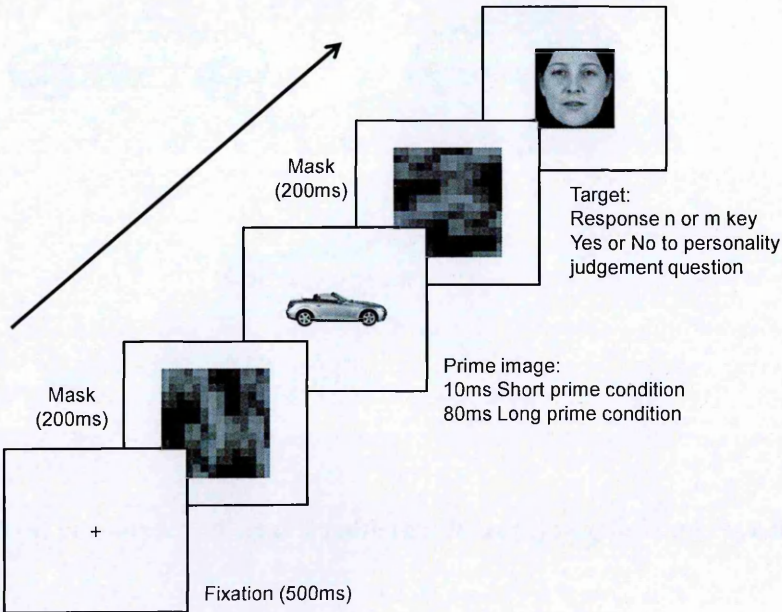


Figure 10-3. Prime-target sequence

Prior to the main experimental sequence participants completed a practice block involving a single personality item (not used further in the study) and thirty faces. Participation concluded with an image recognition task. Figure 10-5 shows the overall sequence of the experiment for each participant. Table 10-1 shows the ten personality items and two status items (the same as those used in Studies 7, 8 and 9).



Figure 10-4. Six of the 60 face images used. Upper row: female faces; Lower row: male faces

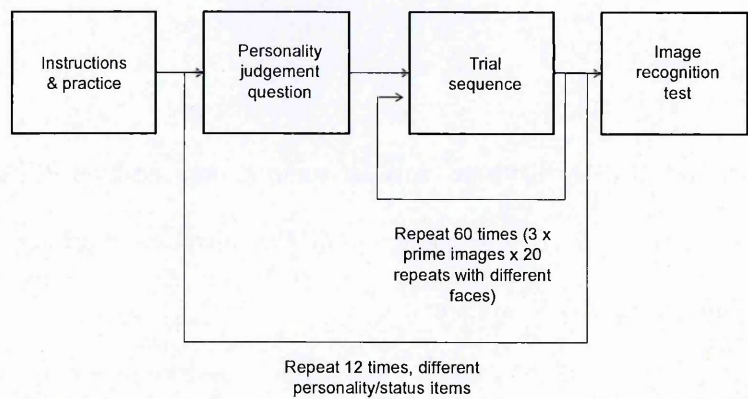


Figure 10-5. Overall sequence of the experiment for each participant

Recognition of prime images

At the conclusion of the main task, participants were shown the three prime images and three previously unseen images of similar subjects (different light bulb, small hatchback and sports car), and were asked whether they had seen each image during the experiment, and to rate their

confidence in each of these answers on a 7-point scale (with verbal anchors for scale points 1 (“not at all confident”) and 7 (“very confident”)).

Five-factor trait, or status	Items
Openness	Sees beauty in things that others might not notice
	Prefers to stick to things that he or she knows
Conscientiousness	Likes to tidy up
	Makes rash decisions
Extraversion	Has a lot of fun
	Feels uncomfortable around people
Agreeableness	Sympathises with the homeless
	Gets back at others
Neuroticism	Feels able to deal with things
	Worries about things
Status	Has a low status job
	Has a high income

Table 10-1. Personality and status items

Equipment & software

The task was programmed using E-Prime software running on a desktop PC. The screen refresh rate of the PC monitor was < 85Hz, fast enough to display images and primes for the appropriate durations. The screen size was 37.5 × 47.5 cm.

To control for laterality bias, two versions of the programme were used, one in which the “yes” response was given with the “n” key on the keyboard and the “no” response with the “m” key, and the other with these assignments reversed. These versions were used alternately so that in each condition, half the participants used each.

Participants

The 51 participants (38 female, 13 male) were undergraduate students on psychology courses at Bangor University (UK), and participated for course credits. The mean age of the sample was 20.9 ± 1.3 years. Participants were randomly assigned to the *short prime* and *long prime* conditions.

Analysis

Data consisted of 720 recorded judgments for each participant (20 judgments for each prime x personality/status item). Judgments made with response times shorter than 200ms or longer than 3000ms were excluded, and the fraction of “yes” responses among the remaining valid responses from each set of 20 was calculated to give a score (ranging from 0.0 to 1.0) for each prime x personality/status item for each participant. Analysis of variance was carried out for each item with *prime type* as the independent variable. Mean scores for the two experimental primes were normalized against the mean score for the control prime for that item (by calculating the ratio of two, so that a score for an experimental prime that equalled the mean score for the control prime had a normalized score of 1.0), and a final score for each experimental prime type on each personality trait (and status) was calculated using the formula:

$$Trait\ score = \frac{1}{2} \left(NS_{pos} + \left(\frac{1}{NS_{neg}} \right) \right) \quad \dots (10.1)$$

where NS_{pos} is the normalized score for the positively valenced item of the pair relating to a particular trait, and NS_{neg} is the normalized score for the negatively valenced item.

Results

Table 10-2 shows the mean scores on each item for each prime image, in the *short prime* condition ($n = 26$). Figure 10-6 shows the combined scores for each 5-factor trait and for status. The small hatchback exhibited no statistically significant associations (relative to control). The sports car exhibited no significant associations with openness, conscientiousness, extraversion, neuroticism or status. Mean response to the agreeableness item *sympathise with the homeless* was significantly lower than control, although mean response for the other agreeableness item *get back at others* was not significantly different.

Item	Mean Score			Mean score, relative to Control			ANOVA	
	Control (light-bulb)	Small hatch-back	Sports-car	Small hatch-back	Sports-car	Df	F	p
See beauty in things that others might not notice	0.46	0.49	0.48	1.06	1.03		N/S	
Prefer to stick with things that he or she knows	0.51	0.55	0.58	1.07	1.14		N/S	
Likes to tidy up	0.55	0.51	0.54	0.89	0.97		N/S	
Make rash decisions	0.40	0.41	0.39	1.02	0.96		N/S	
Have a lot of fun	0.45	0.42	0.45	0.95	1.01		N/S	
Feel uncomfortable around people	0.43	0.46	0.44	1.07	1.02		N/S	
Sympathise with the homeless	0.50	0.50	0.44*	0.99	0.87	2, 1489	2.89	0.05
Get back at others	0.45	0.47	0.48	1.06	1.07		N/S	
Feel able to deal with things	0.63	0.61	0.64	0.96	1.02		N/S	
Worry about things	0.56	0.57	0.54	1.02	0.97		N/S	
Have a high income	0.48	0.46	0.46	0.95	0.95		N/S	
Have a low status job	0.48	0.45	0.46	0.93	0.97		N/S	

Table 10-2. Mean scores on each item for each prime image, in the *short prime* condition. Scores for experimental primes are also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p < 0.05$).

Item	Mean Score			Mean score, relative to Control			ANOVA	
	Control (light-bulb)	Small hatch-back	Sports-car	Small hatch-back	Sports-car	Df	F	p
See beauty in things that others might not notice	0.53	0.52	0.46*	0.97	0.86	2, 1429	3.56	0.04
Prefer to stick with things that he or she knows	0.53	0.55	0.56	1.03	1.04		N/S	
Likes to tidy up	0.51	0.51	0.47	1.00	0.94		N/S	
Make rash decisions	0.42	0.44	0.46	1.04	1.09		N/S	
Have a lot of fun	0.46	0.44	0.55*	0.94	1.20	2, 1433	5.69	<0.01
Feel uncomfortable around people	0.44	0.42	0.43	0.95	0.99		N/S	
Sympathise with the homeless	0.54	0.53	0.46*	0.97	0.85	2, 1423	3.43	0.04
Get back at others	0.50	0.51	0.54	1.01	1.08		N/S	
Feel able to deal with things	0.55	0.58	0.55	1.05	1.01		N/S	
Worry about things	0.50	0.51	0.52	1.01	1.04		N/S	
Have a high income	0.50	0.50	0.57*	1.01	1.15	2, 1440	3.75	0.02
Have a low status job	0.54	0.49	0.43*	0.91	0.79	2, 1419	5.93	<0.01

Table 10-3. Mean scores on each item for each prime image, in the *long prime* condition. Scores for experimental primes are also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p < 0.05$).

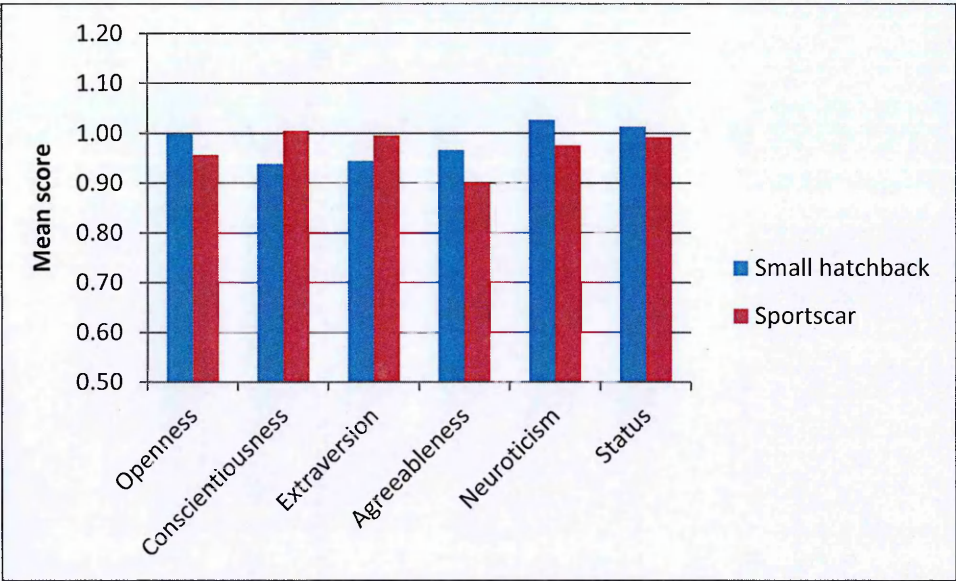


Figure 10-6. Experiment A, *short prime* condition: measured associations between the schemata *small hatchback*; *sports car*, and five-factor personality traits and status

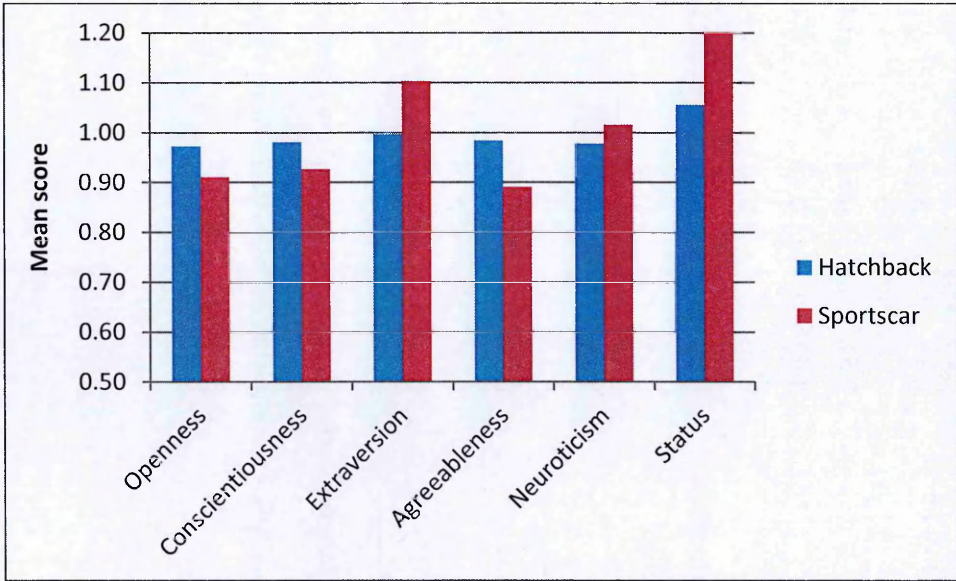


Figure 10-7. Experiment A, *long prime* condition: measured associations between the schemata *small hatchback*; *sports car*, and five-factor personality traits and status

Table 10-3 shows the mean scores on each item for each prime image, in the *long prime* condition ($n = 25$). Figure 10-7 shows the combined scores for each 5-factor trait and for status. In the long prime condition the combined 5-factor trait and status scores for the hatchback were similar to those for the control. However the combined scores for the sports-car prime were different from those for the control in all but one case (neuroticism). The sports-car was associated with lower openness, lower conscientiousness, higher extraversion and lower agreeableness (relative to control), and also with higher status.

Recognition of prime images

Image	% of participants reporting recognition of image		Mean rating of confidence in report (scale 1-7)	
	Short Prime	Long Prime	Short Prime	Long Prime
Control (light-bulb)	61.5	76.0	5.23	6.16
Hatch-back	57.7	52.0	5.19	5.76
Sports-car	76.9	84.0	5.62	5.56
Unseen light-bulb	38.5	40.0	5.69	5.84
Unseen hatch-back	26.9	12.0	5.23	5.80
Unseen sports-car	15.4	12.0	5.35	5.80

Table 10-4. Post-experiment recognition of prime and unseen images

Table 10-4 shows the mean scores and mean confidence ratings for post-experiment recognition of the prime images, plus the set of similar been unseen images, for both the short prime and long prime conditions. A majority of participants reported that they had seen the prime images in both conditions, although the percentages were higher in the long prime condition. A minority, but a substantial one, reported that they had seen the unseen images. The percentages were lower for the unseen hatch-back in the long prime condition, but were similar for the other two unseen images.

Among the images themselves, there was a pattern, repeated across the short prime and long prime conditions. Recognition of the sports-car prime image was reported by a higher percentage of participants, followed by the control light-bulb prime image; recognition of the hatch-back prime image was reported by fewer participants (and in fact by even fewer in the long prime than the short prime condition). Among the unseen images, the unseen light-bulb was reported as having been seen by around 40% of participants, followed by the unseen hatch-back, with few participants reporting recognition of the unseen sports-car.

Discussion

Significant effects were observed in the long prime condition but not in the short prime condition. This supports the theoretical position outlined earlier, that representations of personality traits and status are associated with the fully integrated concepts, *sports car* and *small hatchback*, and it is only when recurrent and feedback processing of the prime proceeds far enough for the representation of one of these concepts to be activated that activation can spread further to representations of personality traits and status.

The pattern of findings for *sports car* in long prime condition broadly reflects the pattern found with the explicit attribution-vignette method (Study 7). This suggests that with the 80ms prime there was sufficient activation of the category *sports car* for activation to spread to its associated symbolic meanings in the form of personality and status representations.

However the pattern of findings for the small hatch-back was weaker than that found with the attribution-vignette method. This could reflect differences in symbolic meaning for different participant groups. In Study 7 (which also measured attributions of age & gender), small hatch-backs were attributed to younger drivers and females; however the predominantly young female sample in Experiment 10 may have had different attributions. Alternatively, since Table 10-4 shows that participants' recognition of the small hatchback image was lower than that of the sports car, it may be that even in the long prime condition, there was insufficient processing to enable specific activation of the category representation of *small hatchback*, and spreading of activation from that to semantically associated personality representations.

Given that participants were presented with each prime image 240 times it is perhaps not surprising that there was some post-experiment recognition of the prime images, even though they were masked on each presentation. Lamme (2003) suggests that visual processing for 100-150ms can lead to phenomenal awareness, where percept representations are activated (and able to spread their activation to associated representations), but conscious report is not possible. After processing for 200-300ms, recurrent interactions grow more widespread, and eventually include areas in the frontal, prefrontal and temporal cortex involved in executive function and memory, such that the visual information can be contextualized in relation to current goals and history. This leads to access awareness, when the individual is able to make a conscious report.

It may be that some small degree of persisting activation of the integrated percept accumulated over multiple trials to such an extent that access awareness became possible on later trials. Consistent with this, post-experiment recognition was higher in the long prime than the short prime condition, though even in the long prime condition it was low for the small hatchback image. Participants were also, to some extent, able to distinguish the unseen from the prime images, particularly in the case of the sports car. This suggests that certain object percepts are more immediately recognizable, with less processing, than others, and that the *sports car* was a particularly recognizable percept for these participants.

An alternative explanation is that access awareness was not achieved during the trials themselves, but that sufficient activation of the percept representation persisted at the end of the experiment to enable recognition of the image when presented without time constraint.

If access awareness of the later prime images did occur, learning effects could have impacted on participants' personality judgments, particularly in later trials. However the randomised presentation of combinations of face images, primes and personality/status items controlled for such learning effects, so they could not affect the overall results.

Experiment 11

Experiment 10 demonstrated the potential of the experimental paradigm, but the symbolic meanings attributed to vehicle categories by a sample consisting largely of young female university students (probably mostly not currently regular car users) might not have reflected those shared by wider the wider UK driving population. Accordingly in Experiment 11 the study was repeated with a more population-representative sample, and was extended to include the complete range of vehicle categories whose symbolic meanings were measured in Study 7.

Method

The method was the same as for Experiment 10, with the following changes:

1. Prime duration: there was only one prime duration condition, 100ms. This was extended from the 80ms used in the long prime condition of Experiment 10 to enable slightly more time for extended visual processing.
2. Vehicle category pairs: Participants were allocated to one of four equal-sized groups. Each group received a different set of prime image stimuli (with the same control, an image of a light bulb, as used in Experiment 10):
 - Pair A: small hatchback, sports car
 - Pair B: executive saloon, van
 - Pair C: medium hatchback, MPV (people carrier)
 - Pair D: medium hatchback, SUV
3. Participants: Participants were 40 males and 40 females, in the age range 35-55. All were current drivers, with an annual mileage of 5000 miles or more, with normal or corrected-to-normal vision. Ten participants of each gender were randomly allocated to each group.

Item	Mean Score			Mean score, relative to Control			ANOVA		
	Control (light-bulb)	Small hatch-back	Sports-car	Small hatch-back	Sports-car	Df	F	p	
See beauty in things that others might not notice	0.41	0.41	0.35*	1.01	0.85	2, 1417	5.93	<0.01	
Prefer to stick with things that he or she knows	0.50	0.47*	0.53*	0.92	1.06	2, 1425	4.73	0.01	
Likes to tidy up	0.53	0.52	0.50	0.98	0.95		N/S		
Make rash decisions	0.42	0.44	0.41	1.06	0.98		N/S		
Have a lot of fun	0.41	0.43	0.43	1.04	1.04		N/S		
Feel uncomfortable around people	0.34	0.34	0.32	0.99	0.94		N/S		
Sympathise with the homeless	0.47	0.49	0.41*	1.04	0.87	2, 1410	4.61	<0.01	
Get back at others	0.48	0.48	0.52	1.01	1.08		N/S		
Feel able to deal with things	0.63	0.65	0.62	1.03	1.00		N/S		
Worry about things	0.47	0.52*	0.43*	1.11	0.92	2, 1438	6.13	<0.01	
Have a high income	0.46	0.45	0.51*	0.98	1.12	2, 1434	4.87	0.01	
Have a low status job	0.47	0.49	0.43*	1.03	0.91	2, 1429	3.82	0.02	

Table 10-5. Experiment 11, Pair A. Mean scores on each item for each prime type (control, small hatchback and sports car). Scores for each vehicle prime are also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p < 0.05$).

Item	Mean Score			Mean score, relative to Control			ANOVA		
	Control (light-bulb)	Executive saloon	Van	Executive saloon	Van	Df	F	p	
See beauty in things that others might not notice	0.49	0.49	0.46	1.00	0.95		N/S		
Prefer to stick with things that he or she knows	0.56	0.56	0.58	1.00	1.03		N/S		
Likes to tidy up	0.57	0.61	0.58	1.07	1.01		N/S		
Make rash decisions	0.40	0.38	0.40	0.95	1.01		N/S		
Have a lot of fun	0.61	0.57	0.58	0.92	0.95		N/S		
Feel uncomfortable around people	0.39	0.39	0.43*	1.00	1.09	2, 1426	3.06	0.05	
Sympathise with the homeless	0.54	0.57	0.49*	1.05	0.90	2, 1435	5.47	0.01	
Get back at others	0.49	0.48	0.52	0.98	1.06		N/S		
Feel able to deal with things	0.65	0.65	0.65	1.00	1.00		N/S		
Worry about things	0.49	0.49	0.51	1.00	1.04		N/S		
Have a high income	0.58	0.66*	0.57	1.14	0.99	2, 1411	5.39	0.01	
Have a low status job	0.40	0.40	0.48*	0.99	1.19	2, 1444	6.24	<0.01	

Table 10-6. Experiment 11, Pair B. Mean scores on each item for each prime type (control, executive saloon and van). Scores for each vehicle prime are also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p < 0.05$).

Item	Mean Score			Mean score, relative to Control			ANOVA	
	Control (light-bulb)	Medium hatch-back	People carrier (MPV)	Medium hatch-back	People carrier (MPV)	Df	F	p
See beauty in things that others might not notice	0.52	0.51	0.54	0.98	1.03		N/S	
Prefer to stick with things that he or she knows	0.51	0.54	0.50	1.05	0.98		N/S	
Likes to tidy up	0.53	0.53	0.54	1.00	1.02		N/S	
Make rash decisions	0.35	0.33	0.32	0.95	0.92		N/S	
Have a lot of fun	0.44	0.45	0.51*	1.04	1.17	2, 1428	4.39	0.02
Feel uncomfortable around people	0.46	0.47	0.49	1.02	1.06		N/S	
Sympathise with the homeless	0.54	0.57	0.52	1.07	0.98		N/S	
Get back at others	0.55	0.55	0.55	0.99	0.99		N/S	
Feel able to deal with things	0.59	0.59	0.62	1.00	1.06		N/S	
Worry about things	0.53	0.56	0.56	1.04	1.05		N/S	
Have a high income	0.46	0.45	0.51*	0.98	1.09	2, 1462	3.57	0.04
Have a low status job	0.43	0.44	0.36*	1.03	0.85	2, 1431	5.87	<0.01

Table 10-7. Experiment 11, Pair C. Mean scores on each item for each prime type (control, medium hatchback and people carrier (MPV)). Scores for each vehicle prime are also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p < 0.05$).

Item	Mean Score			Mean score, relative to Control			ANOVA		
	Control (light-bulb)	Medium hatch-back	SUV	Medium hatch-back	SUV	Df	F	p	
See beauty in things that others might not notice	0.59	0.56*	0.50*	0.94	0.85	2, 1463	5.43	0.01	
Prefer to stick with things that he or she knows	0.64	0.63	0.59	0.98	0.92		N/S		
Likes to tidy up	0.53	0.56	0.51	1.04	0.95		N/S		
Make rash decisions	0.44	0.38*	0.41*	0.86	0.92	2, 1455	4.79	0.02	
Have a lot of fun	0.52	0.51	0.56*	0.98	1.08	2, 1423	3.19	0.04	
Feel uncomfortable around people	0.38	0.36	0.47*	0.94	1.23	2, 1412	6.54	<0.01	
Sympathise with the homeless	0.58	0.63	0.48*	1.07	0.83	2, 1445	6.36	<0.01	
Get back at others	0.48	0.45*	0.50	0.94	1.04		N/S		
Feel able to deal with things	0.68	0.68	0.69	1.00	1.02		N/S		
Worry about things	0.55	0.56	0.52	1.01	0.94		N/S		
Have a high income	0.43	0.44	0.51*	1.03	1.20	2, 1421	6.24	<0.01	
Have a low status job	0.51	0.51	0.46*	0.99	0.89	2, 1426	3.23	0.04	

Table 10-8. Experiment 11, Pair D. Mean scores on each item for each prime type (control, medium hatchback and (SUV)). Scores for each vehicle prime are

also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p <$

0.05).

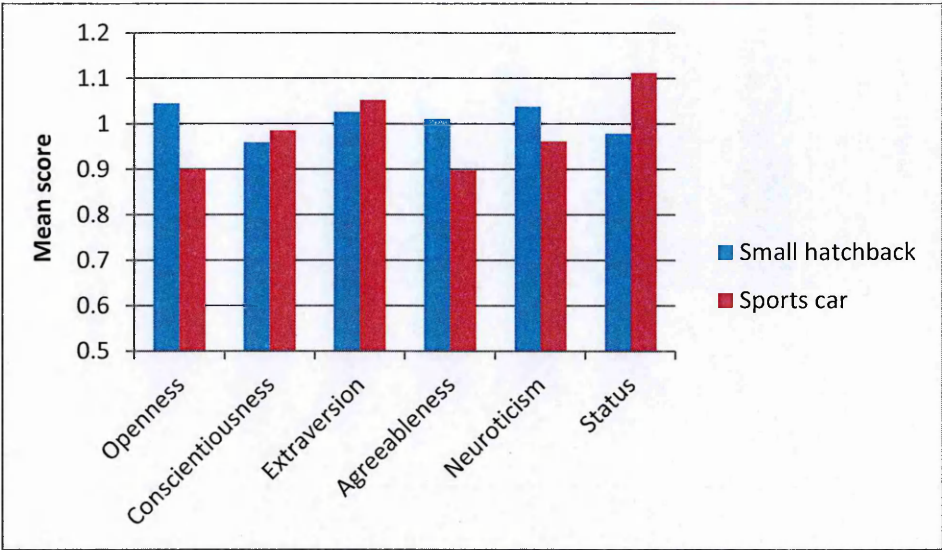


Figure 10-8. Experiment 11, Pair A: measured associations between the schemata *small hatchback*; *sports car*, and five-factor personality traits and status

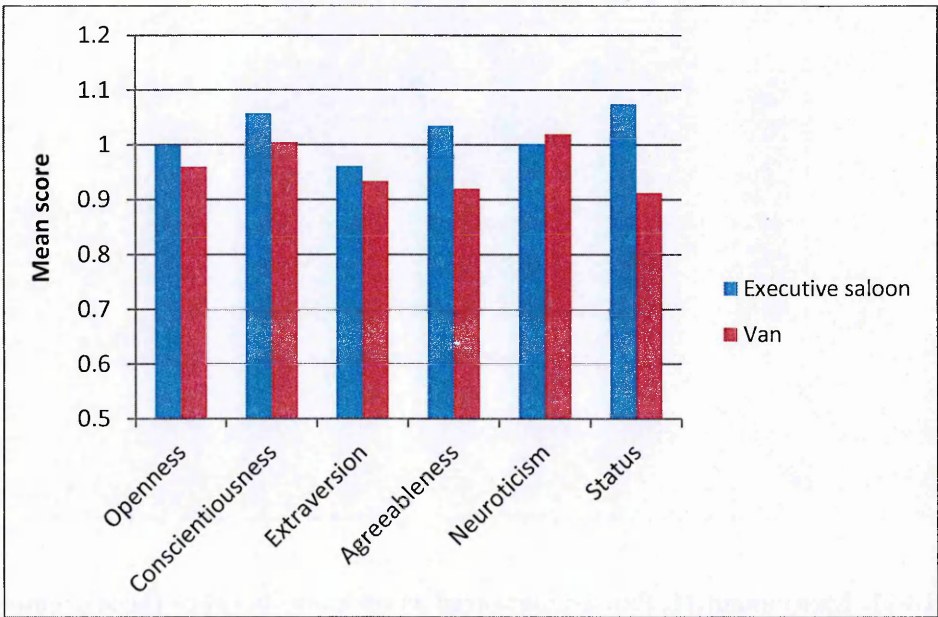


Figure 10-9. Experiment 11, Pair B: measured associations between the schemata *executive saloon*; *van*, and five-factor personality traits and status

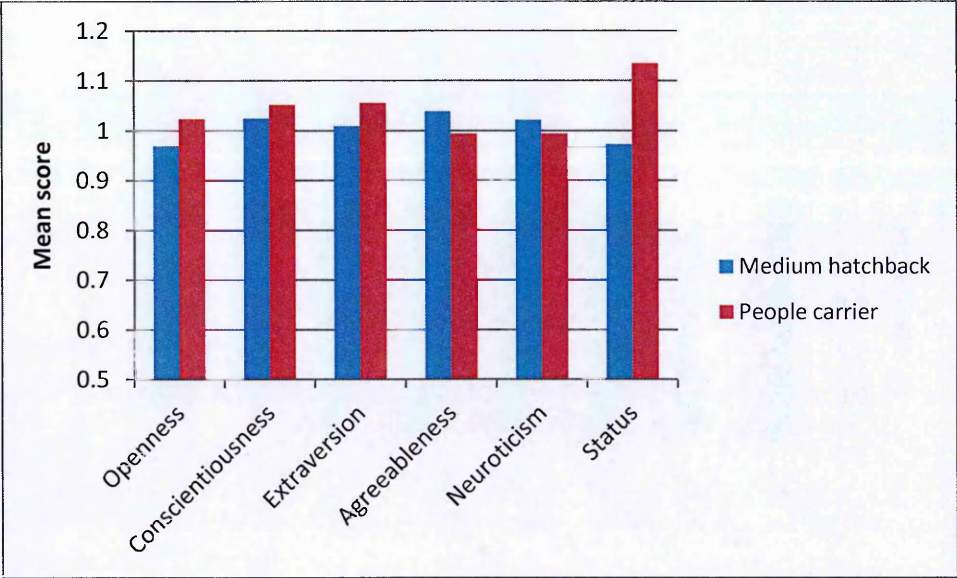


Figure 10-10. Experiment 11, Pair C: measured associations between the schemata *medium hatchback*; *people carrier (MPV)*, and five-factor personality traits and status

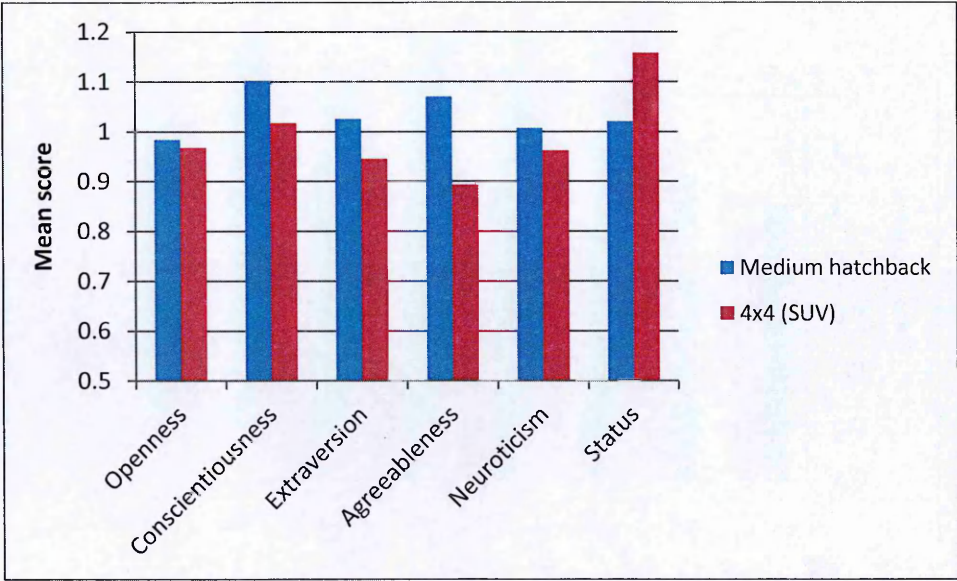


Figure 10-11. Experiment 11, Pair D: measured associations between the schemata *medium hatchback*; *SUV*, and five-factor personality traits and status

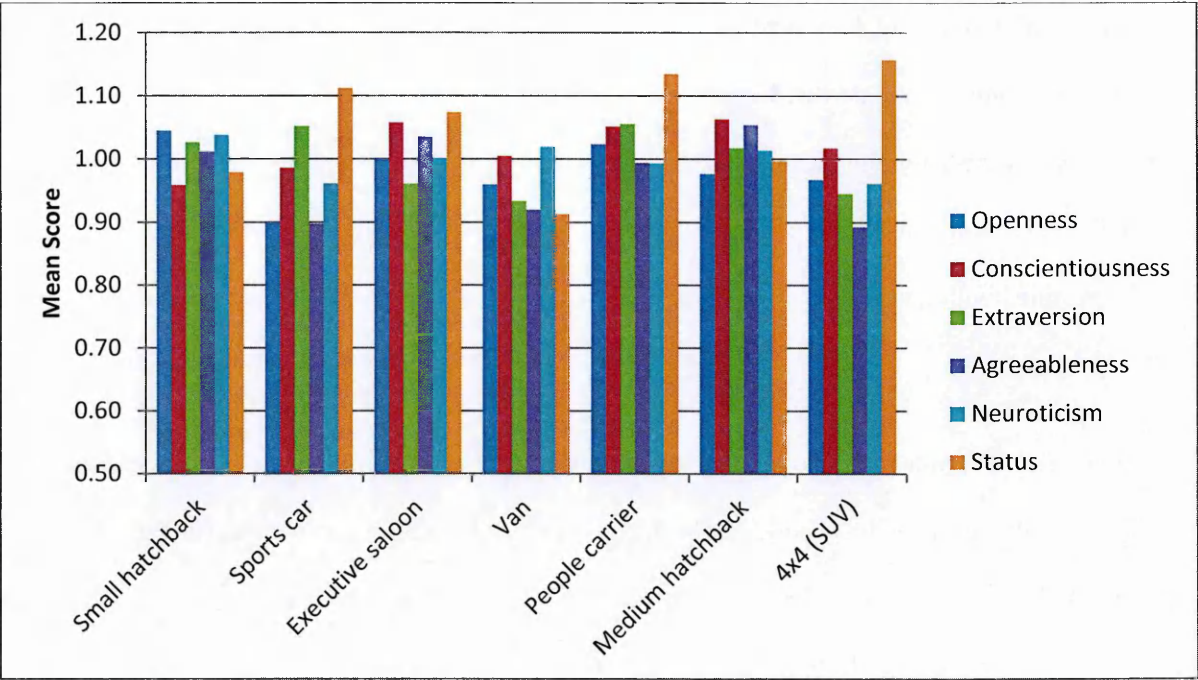


Figure 10-12. Experiment 11 summary: measured associations between the schemata *small hatchback, sports car, executive saloon, van, people carrier, medium hatchback SUV, and five-factor personality traits and status*

Results

Tables 10-5 to 10-8 and Figures 10-8 to 10-11 show the results for each pair of vehicles, and Figure 10-12 summarises all the results in one chart. Neither the small hatchback nor the medium (family) hatchback was significantly associated with any of the personality traits, nor with status. Nor were the executive saloon and MPV (people carrier) significantly associated with personality traits, though both were associated with high status, the MPV more so than the executive saloon. The SUV was associated with low agreeableness and high status, while the sports car was associated with low openness, low agreeableness and high status. Extraversion was also high relative to control for the sports car, but this was not significant.

Discussion

The pattern of results for the small hatchback was similar to that obtained in the long prime condition in Experiment 10. The pattern of results for the sports car was also similar in most

respects (high status, high extraversion, low agreeableness) though in Experiment 11 the sports car was significantly associated with openness, which it was not in Experiment 10. This may reflect a difference in the symbolic meaning of the sports car between the two sample groups, given that the sample in Experiment 10 was composed mainly of young women students while that in Experiment 11 contained both genders and was more representative of the general driving population in terms of car use and age.

The pattern of results was also in broad agreement with that obtained using the explicit attribution-vignette method in Study 7, particularly in respect of status and agreeableness (though there were some differences – notably that MPV drivers were not attributed high status in Study 7, but the MPV was associated with high status in Experiment 11). In Study 7, high conscientiousness was attributed to MPV drivers, and low conscientiousness to van and sports car drivers; in Experiment 11 there was a non-significant positive association between the MPV and conscientiousness, but the negative associations with van and sports car were not found. Although the effect sizes in the two methods cannot be directly compared, it appears generally that similar results were obtained, but that the associations measured in Experiment 11 for most personality traits were directionally similar but somewhat weaker than the attributions made in Study 7. This was not the case for agreeableness or status, suggesting that these associations are relatively the strongest, at least for certain vehicle categories. It may also be, however, that the 100ms prime duration may have been insufficient for full recognition of some of the vehicle categories: the two hatchbacks and the executive saloon may not have been clearly recognized as distinct categories in the processing time available.

Experiment 12

In Experiments 10 and 11 the priming method was used to measure implicit associations between vehicle categories and personality traits and status, using images of vehicles as the primes. The same method cannot, however, be applied to schemata that cannot be represented in easily recognized images – for instance, the performance attributes and driving styles of Studies 8 and 9.

To measure associations between such schemata and personality traits and status, an extension to the method was developed in Experiment 12, in which participants were first trained to associate the non-visual categories with images of arbitrary symbols, and then these symbols were used as primes. The experiment sought to measure associations between personality traits and status on the one hand, and the dynamic performance attribute *fast acceleration*, and the combined cruising performance attributes *quiet and smooth* on the other.

Method

Experiment 12 involved two stages: a *learning symbols* task, followed by the same *judging personalities* task used in Experiments 10 and 11.

Learning symbols task

In the first part of the computerized session, participants learnt to associate three arbitrary visual symbols with written phrases. Two of the written phrases described vehicle performance attributes. The third was a neutral control phrase consisting on nonsense words. The three phrases were:

- Car that accelerates fast
- Car that's quiet and smooth
- Mol fuab tepor duptog zee

Figure 10-13 shows the three symbols. There were six possible (symbol \times phrase) combinations, and multiple versions of the E-Prime programme used each of these combinations (there were twelve versions overall, two for each of these combinations, as there were also two versions of the judging personality task, with opposite response keys).

Participants were first shown a screen in which all three symbols were presented together, with the associated phrases underneath. They were given as long as they chose to learn the pairings. Participants then proceeded to two tests, which simultaneously reinforced and tested their learning. Figure 10-14 shows the sequence.

In test 1, participants were shown the three symbols, together with one of the phrases, and had to choose which symbol went with that phrase. They received feedback on whether their response was

correct. A correct response earned the participant 50 points; incorrect responses lost all points earned. Participants were then reminded of the correct association, before repeating the task. To complete the test, participants had to respond correctly 15 times in succession. Any error reset the counter to zero. If participants have not achieved 15 correct responses in succession after ten minutes, the programme concluded test 1 and moved to test 2.

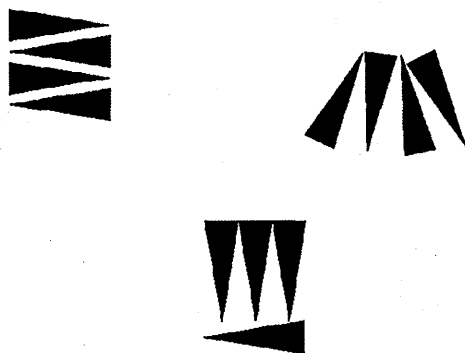


Figure 10-13. Prime symbols

In test 2, the logic of test 1 was reversed. Participants were shown the three phrases, together with one of the symbols, and had to choose which phrase went with that symbol. As in test 1, they received feedback on whether their response was correct. A correct response earned the participant 50 points; incorrect responses lost all points earned. Participants were then reminded of the correct association, before repeating the task. To complete the test, participants had to respond correctly 15 times in succession. Any error resets the counter to zero. If participants had not achieved 15 correct responses in succession after ten minutes, the programme concluded the learning symbols task.

Participants proceed to the judging personalities task when they had passed both test 1 and test 2. Participants who had failed to complete either test 1 or test 2 within 10 minutes were thanked at the end of test 2 but did not proceed to the judging personalities task.

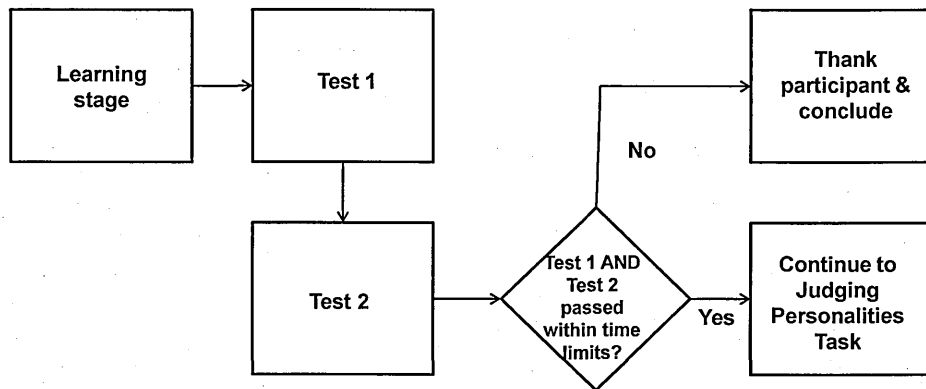


Figure 10-14. Experiment 12: Learn and test sequence, learning symbols task

Judging personalities task

The judging personalities task was the same as used in Experiments 10 and 11. As in Experiment 11 there was a single prime duration, this time increased further to 120ms to enable slightly more time for feedback and recurrent processing to occur.

To control for the possibility that some feature(s) in the arbitrary symbol images might in fact have its own symbolic associations, there were separate versions of the programme for each possible combination of symbol and phrase, and the thirty-six participants were randomly assigned to six equally-sized groups, each of which used a different version.

To control for laterality bias, two versions of each symbol-phrase variant programme were used, one in which the “yes” response was given with the “v” key on the keyboard and the “no” response with the “n” key, and the other with these assignments reversed. These versions were used alternately so that in each group, half the participants used each.

Participants

Thirty-six participants were recruited according to the same criteria as in Experiment B: i.e. they were intended to be a sample representative of the general UK driving population. Eighteen were female and eighteen male; their ages ranged from 30-55. Of this original group, one male and one female failed to complete the learning symbols task. They were replaced with a further two participants, one of each gender, to ensure balanced data from six participants in each symbol-phrase group.

Results

The results for each item are shown in Table 10-9 and the combined results for each personality trait, and status, are summarized in Figure 10-15. *Car that's quiet and smooth* was directionally associated with higher conscientiousness and agreeableness than the control phrase, though the only statistically significant result was for the agreeableness item *sympathises with the homeless*. Car that accelerates fast was associated with low conscientiousness, low neuroticism and low agreeableness (with one significant item in each case). Neither of the performance concepts was associated with status, high or low.

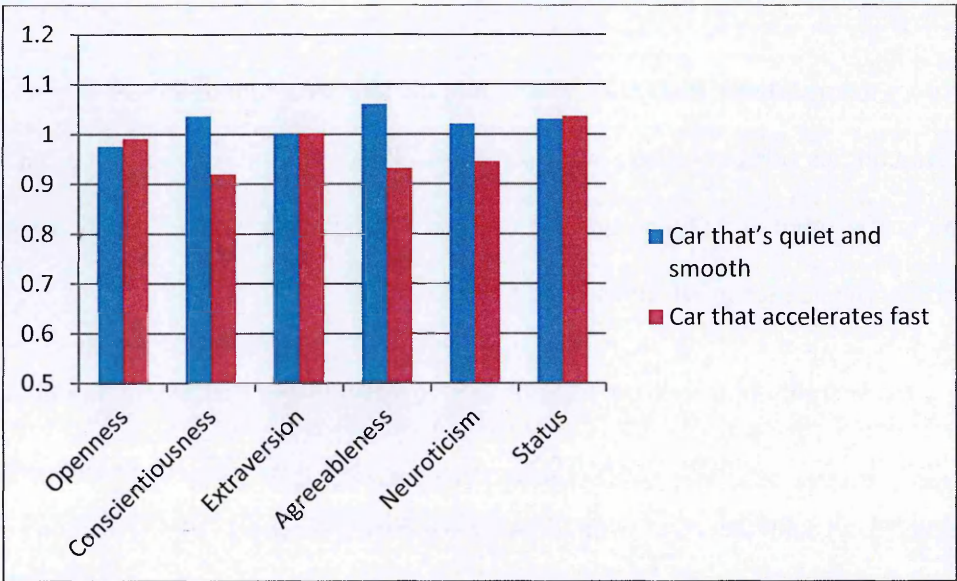


Figure 10-15. Experiment 12: measured associations between the schemata *car that accelerates very fast*; *car that's quiet and smooth*, and five-factor personality traits and status

Item	Mean Score			Mean score, relative to Control			ANOVA	
	Control (light-bulb)	Car that's quiet and smooth	Car that accelerates fast	Car that's quiet and smooth	Car that accelerates fast	Df	F	p
See beauty in things that others might not notice	0.54	0.51	0.51	0.95	0.95		N/S	
Prefer to stick with things that he or she knows	0.57	0.57	0.55	1.00	0.97		N/S	
Likes to tidy up	0.54	0.56	0.50	1.04	0.93		N/S	
Make rash decisions	0.39	0.38	0.43*	0.97	1.10	2, 1418	4.43	0.02
Have a lot of fun	0.52	0.52	0.54	0.99	1.04		N/S	
Feel uncomfortable around people	0.34	0.34	0.36	0.99	1.04		N/S	
Sympathise with the homeless	0.51	0.56*	0.47*	1.10	0.92	2, 1428	5.78	<0.01
Get back at others	0.48	0.47	0.51	0.98	1.06		N/S	
Feel able to deal with things	0.72	0.72	0.73	1.00	1.01		N/S	
Worry about things	0.44	0.46	0.40*	1.04	0.90	2, 1437	4.84	0.01
Have a high income	0.49	0.52	0.51	1.07	1.04		N/S	
Have a low status job	0.37	0.37	0.36	1.01	0.97		N/S	

Table 10-9. Experiment 12. Mean scores on each item for each prime type. Scores for each experimental prime are also shown relative to the scores for the control prime. N/S = not significant; asterisk indicates statistically significant difference from control (post-hoc, $p < 0.05$).

Discussion

These results broadly agree with those obtained with the attribution-vignette method in Study 8. It is perhaps notable that the null result for status agrees with that in Study 8.

The associations appear to have been generally weaker than those found for vehicle categories in Experiment 11. This is perhaps not surprising, given the extra associative step involved: from symbol to concept to associated personality trait or status, rather than simply from concept to associated personality trait or status. We might also surmise that the symbol-concept associations, only recently learned, might be weaker than concept-trait associations that may have been reinforced over extended periods.

General discussion

The findings in these experiments can be interpreted from the perspective of spreading activation (Anderson, 1976, 1983a, 1983b, 1993; McNamara, 2005; Neely, 1997; Wittenbrink, 2007), and more specifically interactive activation and competition models (Davis, 2003; McClelland & Rumelhart, 1981). Visual processing of the prime image causes activation of a concept representation in memory (e.g. of a sports car). Activation then spreads from that representation to associated representations. Adopting an interactive activation and competition perspective, then excitation spreads to associated representations, and inhibitory signals to competing representations. Some concepts have symbolic meanings associated with them, and so are associated with particular combinations of personality traits and status. I assume that neither personality traits nor status are represented by single nodes in the semantic network, but rather in some way that represents a scale. A simple model for this might be two mutually inhibitory nodes for each pole of a scale, say *high agreeableness* – *low agreeableness*. Activation of a concept might cause, for example, excitation of the low agreeableness node and inhibition of the high agreeableness node; and both nodes also inhibit each other, with inhibition strengths depending on their net activations. The asymptotic relative activations of these nodes when the network has settled represent a particular position on a “mental scale” of agreeableness. Thus a pattern of

activation is established, by the prime, for each of the trait representations. During the subsequent judging personality task, the participant attempts to use visual information from the image of a face to attribute a personality trait. This may involve, for instance, recognizing a facial feature that has some association with the trait. Activation of the representation of that feature will activate its own trait associations - i.e. spread the feature-appropriate combination of excitation and inhibition to the high and low trait nodes. However following the priming those nodes will not be in their resting states but will have a primed pattern of activation to which the new inhibitory and excitatory inputs will be summed. The network will sum to a new asymptotic activation pattern across the high and low nodes that has been influenced by the prime-trait associations. It is this pattern, modified by the prime, that is accessed to determine the personality judgment response.

One feature of such a model is that priming effects should depend on the prime having been recognized, so that its concept is activated and can in turn spread its excitatory and inhibitory signals. That leads to a prediction that if a prime is presented for a duration that is too short for the prime to be recognized, no priming will result – which appears to have been the case for the 15ms duration primes in Experiment 10. Further, primes may vary in terms of recognisability (for instance, possession of distinctive visual features) so that some can be recognized more readily after shorter processing times but others require more extended processing. This should lead to differential activation of their respective concept representations if processing is interrupted by backward masking before the less recognizable primes have been unambiguously identified. This seems a plausible explanation for the weaker results for categories like *small hatchback*, *family hatchback* or *executive saloon*, that subjectively seem to be less distinctive than, say, *sports car* or *van*.

Personality and status information in face images and control prime image

It was intended that the set of face images should be neutral with respect to information content about personality traits and status, and also that the control image (the light bulb) should not prime personality trait or status representations. If this were the case then the means of responses to each personality and status item when primed with the control image should all have been 0.5. Table 10-10 shows these means (and standard deviations) pooled from all three experiments. The means for

most items were close to 0.5; means for the items *make rash decisions* and *feel uncomfortable around people* were lower (0.4), and the mean for the item *feel able to deal with things* was higher (0.64). For these three items, some information about personality or status must have been conveyed by either the control prime image or the set of faces. Some studies have found evidence of small but statistically significant accuracy in making personality judgments solely from viewing face images (Kramer & Ward, 2010; Little & Perrett, 2007) so it seems more likely that the information was contained in some trait-relevant commonality in facial features across the image pool. However even for the three items where there was some bias across the pool of face images, it was small. Since the mean responses for the experimental primes were measured relative to the mean responses for the control prime, these effects were adequately controlled for in the experimental design.

Item	Mean	Standard deviation
See beauty in things that others might not notice	0.51	0.06
Prefer to stick with things that he or she knows	0.55	0.05
Likes to tidy up	0.54	0.02
Make rash decisions	0.40	0.03
Have a lot of fun	0.49	0.07
Feel uncomfortable around people	0.40	0.05
Sympathise with the homeless	0.53	0.04
Get back at others	0.49	0.03
Feel able to deal with things	0.64	0.06
Worry about things	0.51	0.04
Have a high income	0.49	0.05
Have a low status job	0.46	0.06

Table10-10. Mean responses to each personality trait and status item, control prime condition, pooled across all three experiments

Using symbols as primes

Experiment 12 showed that it is possible for a participant to learn a new association between a concept and an arbitrary symbol, and then to use the symbol as a prime. Priming effects from newly learned associations have been found in word recognition research (Percher & Raaijmakers, 1999). The process involves an extra step in terms of spreading activation. First, the node representing the prime image (symbol) is activated by viewing the prime; then activation spreads along the newly created associative link to the node representing the concept; only then it can spread to related representations of personality traits and status as described above. Mediated priming (where the association between the prime and target is indirect, mediated via other nodes in the semantic network: for example, *mane* and *tiger*, which are not directly associated, but are linked via *lion*) has been shown over both two and three steps (McNamara, 1992, 2005). It is compelling evidence for spreading activation models, and difficult to account for in other models of priming (McNamara, 2005). Such models predict, however, that priming effects will be weaker when mediated. There is some suggestion of this in the findings of Experiment 12, where the effects seem smaller than those in Experiment 11 and the equivalent attribution-vignette measurements in Study 8.

Agreement with attribution-vignette method

There was a reasonable degree of agreement between the results obtained from this series of implicit priming experiments and those obtained using the explicit attribution-vignette method. This enables a degree of confidence that the symbolic meanings identified are not the result of strategic responding (to fulfil a communicative goal of the participant, such as to present the participant in a socially acceptable light) or constructed in the moment, but rather they represent genuine concept-trait associations stored in memory. Since the attribution-vignette method is much simpler to carry out, and can be done in the form of an online survey with large samples, it will generally be the preferred method for the characterization of symbolic meanings of products and their attributes. However the priming method may be of further value for research with products where there is considered to be a risk of strategic responding. The use of the learning symbols task in Experiment 12 to associate an arbitrary visual symbol with a non-visual concept such as the

performance of a product generalises the utility of the priming method - it is not restricted only to products or attributes that can be directly represented visually.

Chapter Eleven. Influence of performance and symbolic meaning on willingness to consider an electric vehicle

Introduction

In the final experiment I bring together the themes developed earlier by investigating how drivers experience the performance and symbolic meaning of the present generation of BEVs, and whether these experiences influence willingness to consider owning a BEV³⁹.

As we saw in Chapter Eight, there is a body of literature exploring stated preferences for alternative fuelled vehicles, including electric vehicles; and the importance of their various attributes has also been investigated in other types of quantitative surveys (Axsen & Kurani, 2013; Carley, Krause, Lane, & Graham, 2013; Delang & Cheng, 2012; Energy Technologies Institute, 2013; Shin, Hong, Jeong, & Lee, 2012; Schuitema et al., 2013). Performance has sometimes been included in such studies, but only in rather limited ways, using researcher-defined constructs such as “top speed” and “time taken to accelerate from 0-60mph”. In addition the symbolic meanings of EVs have not been characterised in any quantitative research to date (although Schuitema et al. (2013) and Axsen and Kurani (2013) have investigated the role of symbolic motivations in EV and PHEV choices).

The usefulness of quantitative studies to date is somewhat limited, in any case, because their participants have generally had no direct experience of using electric vehicles to draw on when making their responses. Assessment of consumers’ preferences for “really new” product categories can be methodologically challenging (Hoeffler, 2003). Construal Level Theory (Liberman et al., 2007; Trope & Liberman, 2003) proposes that *psychological distance* affects the level of abstraction with which a product is construed. An object is psychologically distant when it is

³⁹ This chapter focuses on BEVs in the first instance, since at the time of the field study it describes, there were no PHEVs or E-REVs available on the UK market, so the field study was restricted to BEVs. I shall, however, consider what the implications suggested by the findings for uptake of all types of EVs in the discussion section.

detached from a person's direct experience: the more psychologically distant an object, the more it is construed in high-level, abstract terms, rather than low-level, concrete terms. This suggests that research in which participants have not directly experienced electric vehicles may be subject to large uncertainties.

Further, Unconscious Thought Theory (Dijksterhuis & Nordgren, 2006) suggests that consumers make "better" decisions in relation to product choices when information has been non-consciously processed than when they engage in conscious deliberation. "Better" has been operationalised as closeness to normative decisions (Dijksterhuis & Nordgren, 2006) and as post-choice satisfaction (Dijksterhuis, Bos, Nordegren, & van Baaren, 2006).

In the survey study by the UK Energy Technologies Institute (ETI) (Energy Technologies Institute, 2013; Schuitema et al., 2013), psychological distance was reduced somewhat by providing information about electric vehicles to participants two days before the main survey. The interval provided an opportunity for non-conscious processing during which information could be integrated in long term memory with semantic knowledge about self, lifestyle, cars, driving, the environment, etc. There is, however, no doubt that direct experience is the most effective way to reduce psychological distance. There is (in 2014) a rather limited body of literature exploring drivers' responses to electric vehicles following experience of their use (Axsen & Kurani, 2012; Axsen, Orlebar & Skippon, 2013; Burgess et al., 2013; Caperello, Kurani, & TyreeHageman, 2013; Cocron et al., 2011; Franke & Krems, 2013a; Franke & Krems, 2013b; Graham-Rowe et al., 2012; Golob & Gould, 1998; Gould & Golob, 1998; Jensen et al., 2013; Klockner, Nayum, & Mehmmedoglu, 2013; Skippon & Garwood, 2011).

Even when responses to electric vehicles are elicited from people who have had direct experience of using them, however, there are often two further issues: biased sampling, and Hawthorne effects. The most common sample bias has been that participants have either been amongst the first owners of electric vehicles, or people especially motivated by and interested in them – i.e. actual and

prospective “early adopters”⁴⁰. There is no a priori case to assume that their responses will be representative of the general car user population. Indeed in the ETI’s (2013) segmentation analysis, attitudes towards electric vehicles differed substantially between segments. The attitudes of what the ETI termed the “Pioneer” segment were very much more favourable to electric vehicles, and very un-representative of those of the other segments. This suggests that findings from early adopter samples have limited validity in relation to the wider population (whom I shall refer to henceforth as “mass market consumer drivers” or MMCDs).

A few studies have avoided the “early adopter” bias. Skippon & Garwood (2011) and Axsen et al. (2013) gave participants working for the UK electricity utility company Eon, and Shell’s Technology Centre in the UK, brief direct experiences of using a small hatchback BEV. These samples were not comprised of “early adopters”, but had their own biases: the samples were more highly educated and had higher awareness of environmental issues and electric vehicles than the general UK population. Graham-Rowe et al. (2012), in a qualitative study preceding the ETI’s quantitative survey, gave a diverse sample of 40 UK MMCD households direct experience of using a BEV (Mitsubishi iMiEV or Citroen C1) or PHEV (prototype Toyota Prius PHEV) for a week, with interviews before and after the experience. Finally Jensen et al. (2013) recruited several hundred members of the Danish general public for a study that involved stated preference surveys before and after a three month experience of using a BEV.

⁴⁰ “Early adopter” is a term taken from Rogers’ (2003) diffusion of innovations theory, and strictly refers to those whose time of adoption lies between two and one standard deviations from the mean time to adoption of the population. Those who adopt even earlier (sooner than two standard deviations before the mean adoption time) are termed “Innovators” by Rogers. In the electric vehicle literature, however, this distinction is generally ignored and “Early Adopter” is used for “Innovator” or both. Rather regretfully I conform to this mis-usage here, for consistency with the literature.

Hawthorne effects⁴¹ occur when participants change their behaviours, attitudes or preferences because they are aware they are participating in research, rather than in response to the research stimuli. Controlled studies (in which a control group participates, but does not receive the stimulus) mitigate confounding Hawthorne effects. However they are rare in transport research (Graham-Rowe, Skippon, Gardner, & Abraham, 2011), and so far absent from the electric vehicle literature. The study by Jensen et al. (2013), for instance, while measuring changes in preferences after experiencing use of a BEV, did not control for Hawthorne effects.

Evaluations of EV performance

Axsen et al. (2013) reported participants perceiving that the smoothness of the driving experience with a BEV was a benefit. However there was a mixed response to dynamic performance, with fast acceleration at low speeds seen as a benefit, but poor overall acceleration as a drawback. In their grounded theory analysis, Graham-Rowe et al. (2012) identified a theme *vehicle confidence*, in which participants compared the performance of the electric vehicles they experienced to that of ICE cars: “drivers felt that the power and performance of the EV was substandard” (p.145). Skippon and Garwood (2011) asked participants to rate the performance of the BEV they experienced, using 5-point Likert-type items, in comparison to a conventional small hatchback ICE car, using seven items based on the model of Chapter Three. Participants rated acceleration from 0-30mph as somewhat better, acceleration from 30-50mph as similar, responsiveness as somewhat better, power as somewhat worse, smoothness when cruising as substantially better and noise when cruising as substantially lower than a conventional ICE car. The picture that emerged from these studies was that BEVs were considered by these non-early adopter samples as having better cruising performance, and either worse or at best largely similar dynamic performance (better in some performance attributes but still worse in others). However, all were uncontrolled studies with small or biased samples, using an early generation of BEVs, and, except for Skippon and Garwood (2011), qualitative evaluations. Prior to Experiment 13 there had been no controlled studies using

⁴¹ Named after the location of the factory-based study in which they were first noted.

large samples of MMCDs and quantitative evaluations of dynamic and cruising performance of modern BEVs.

Symbolism of EVs

Heffner et al. (2007) studied symbolism in California's early market for hybrid electric vehicles (HEVs), by analysing owners' qualitative narratives. They found that the personal meanings signified by HEVs included being an ethical person, community orientation, concern for others, intelligence, maturity, sensibility, independence and individuality. Participants were early adopters of HEVs, so while we might expect some commonalities of symbolism, it is risky to extrapolate too much from these findings to the symbolism of EVs among mass-market consumer drivers. Graham-Rowe et al. (2012) identified symbolic meaning as a major theme (referred to as *impression management*) in their participants' responses to the experience of using a BEV or PHEV. Drivers of EVs were perceived as being:

- People with limited mobility needs, for whom the restricted utility of a BEV would not be a problem, and who saw cars from a functional perspective: "sensible and boring ('quite a dull person', 'lacking that sense of fun') and living slow-moving lifestyles" (p.148)
- People who prioritise environmental concerns
- People who derive social identity gains ("kudos") from being seen to adopt new technologies at an early stage

Most participants tended to distance themselves from the first two meanings, but saw the third meaning in a positive light.

Skippon and Garwood (2011) used a version of the attribution-vignette method of Chapter Nine to measure the symbolic meaning of BEVs among their participants. BEV users were seen as being above average in openness, conscientiousness and agreeableness, and average in extraversion and neuroticism.

As outlined in Chapter Eight, self-congruity theory predicts that people will tend to purchase consumer products whose symbolic meanings are congruent with their perceived self-identities.

Schuitema et al. (2013), in their analysis of data from the ETI quantitative survey, found that people with self-reported pro-environmental identities had more positive expectations of EVs than others, while those who saw themselves as authorities on cars did not. Their participants were MMCDs, but without direct experience with EVs (although some steps had been taken to reduce their psychological distance).

This literature tends to suggest that EVs, and particularly BEVs, have symbolic meanings associated with pro-environmental identity, high openness, conscientiousness and agreeableness. They also suggest that people whose self-identities are congruent with these meanings will be more favourably disposed towards EVs than those whose self-congruity is lower. However none of the studies measured the specific symbolic meaning of EVs compared with other vehicle types, or the relationship between self-congruity and potential uptake of EVs, directly with MMCDs who have experienced using an EV themselves.

Field experiment on the influence of performance and symbolic meaning on willingness to consider an electric vehicle

Experiment 13 was designed to measure, rigorously and quantitatively: (1) MMCDs' evaluations of the dynamic and cruising performance of modern (2012) BEVs, (2) the symbolic meanings of BEVs among MMCDs, (3) the potential influence of BEV performance and symbolic meaning on the willingness of MMCDs to consider owning a BEV. The experiment was conducted as a randomized controlled trial (RCT), which enabled assessment of the extent to which participants' responses to BEVs were affected by the reduction in psychological distance associated with the experience of using them, while controlling for Hawthorne effects.

Experiment 13 was part of a wider study measuring attitudes and responses to BEVs, led by the author on behalf of Shell Research Ltd., and carried out by TRL. Findings of the wider study will be published separately. This was, to my knowledge, the first experiment on responses to EVs conducted as an RCT, and the largest study of responses by mass-market consumers with direct experience of using a BEV.

Experiment 13 was concerned with five questions:

1. How do mass-market consumer drivers evaluate the dynamic and cruising performance of modern (2012 model) BEVs, compared with equivalent ICE cars?
2. How do evaluations of the performance of BEVs relate to mass-market consumer drivers' willingness to consider owning a BEV, as a main or second household car?
3. What symbolic meanings do mass-market consumer drivers attribute to BEVs, and do these change after directly experiencing the use of one?
4. How far is the symbolic meaning attributed to BEVs consistent with the symbolic meanings attributed to vehicles of different categories, and vehicles with the same dynamic and cruising performance attributes?
5. Does congruity between personal identity and the symbolic meaning attributed to BEVs impact on mass-market consumer drivers' willingness to consider owning a BEV?

In addition, the opportunity was taken to test a key aspect of the model of how consumer drivers construe vehicle performance, developed in Chapter Three: whether perceived overall performance did indeed depend on perceptions of two independent dimensions, dynamic and cruising performance.

Method

Design

Experiment 13 used a 2×2 mixed factorial design, with one between-participants independent variable (BEV experience) and one within-participants variable (time: before/after experience). Participants were randomly allocated to either an experimental group, who experienced the use of a BEV, or a control group, who experienced the use of an equivalent-sized ICE vehicle. Dependent variables were of three types:

1. Evaluations of the performance of the vehicle used in the experiment, based on the attributes of performance identified in Chapter Three
2. Symbolic meaning of a BEV, measured using the attribution-vignette method of Chapter Nine, before and after the experiment
3. Willingness to consider a BEV as a main or second household car (if the BEV had a range on a full charge of 50, 100, 150, 200 or 250 miles), measured before and after the experiment

In addition, participants completed the IPIP-NEO personality inventory prior to the experiment. In combination with the symbolic meaning data, this enabled a measure of self-congruity to be calculated for each participant.

Participants

Participants were intended to be MMCDs, and specifically *not* people with a special interest in or enthusiasm for electric vehicles (i.e. potential “early adopters”). They were recruited from:

- Direct email to TRL’s volunteer participant pool⁴²
- Adverts on a variety of social media sites including Facebook, Twitter and forums
- Adverts in local doctors’ practices, sports clubs and supermarkets
- Adverts on local companies’ intranet sites
- Word of mouth through TRL employees

This elicited 961 responses, from which a stratified sample was recruited to ensure adequate representation of both genders, a range of participant ages, drivers with low, medium and high mileages, and drivers living in both urban and rural locations. Table 11-1 shows the stratification achieved in the sample.

⁴² A pool of over 1,500 people living within approximately 25 miles of TRL, all of whom have volunteered to take part in research with TRL

Potential participants without access to off-road parking and an off-road external electricity supply at home (for safe recharging) were excluded. Drivers with more than 5 penalty points on their driving licences were also excluded for safety and insurance reasons.

Residence	Age group	Male			Female			Total
		Low mileage ¹	Medium mileage ²	High mileage ³	Low mileage	Medium mileage	High mileage	
Rural ⁴	17-30	8	16	8	6	14	6	58
	31-50	6	18	10	10	24	10	78
	Over 50	8	16	4	4	14	6	52
Urban ⁵	17-30	8	18	8	10	18	8	70
	31-50	8	18	12	10	24	8	80
	Over 50	12	18	8	8	16	4	66
Total		50	104	50	48	110	42	404

Notes:

¹ 5,000 miles per year or fewer

² 5,001-15,000 miles per year

³ Above 15,000 miles per year

⁴ Codes 2, 3 or 4 in the Experian Rural/Urban Code

⁵ Codes 5, 6, 7 or 8 in the Experian Rural/Urban Code

Table 11-1: Experiment 13: stratified sample

Stratification and inclusion/exclusion were achieved via a pre-recruitment questionnaire sent to all 961 positive responders, which contained items on gender, postcode (to determine urban/rural home location), date of birth, annual mileage, off-road parking available at home, external electricity supply available at home, and penalty points on driving licence.

Eleven participants dropped out prior to the use experience. In addition data from two participants was not used as the car they were using broke down during the experiment. A total of 393 participants completed all stages of the experiment.

Stimuli: BEV and control ICE car

Participants in the experimental group were given the use of a Nissan Leaf, a modern “C segment” medium family hatchback BEV with a manufacturer’s claimed range (on a full battery) of 100 miles. Unpublished testing by the author has identified that this range could be achieved with these vehicles in constant driving at 30mph. However in mixed urban and extra-urban driving (repeated NEDC test cycles) it reduced to 83 miles and in constant 75mph driving it reduced to only 44 miles. Recharging a fully discharged battery to the fully charged condition by connecting the charging cable to a standard UK domestic 13A supply took around 12 hours. Four Nissan Leafs were used in the experiment, all of similar age and mileage.

Participants in the control group were given the use of a 1.8l Ford Focus diesel, a modern fuel-efficient “C segment” medium family hatchback ICE car.

Procedure

Participants in the wider study completed three online questionnaires, two before the vehicle experience, and one after. The measures relevant to Experiment 13 were included in the second and third questionnaires, to which I shall refer hereafter as the pre-experience and post-experience questionnaires.

Once recruited, participants were completed the pre-experience questionnaire. They were then contacted by telephone or email to organise a date and time to collect the car. Thus when completing the pre-experience questionnaire they were unaware as to which vehicle they would be experiencing.

Participants collected their cars from TRL. A licence check was conducted on arrival. Participants were then shown the car they had been allocated, briefed on its safe operation, and given the opportunity to drive it under supervision so that they were comfortable with driving it before doing so on their own. They were briefed that they would complete a further questionnaire that would include items on their evaluation of the experience of driving car they had been allocated.

Participants were given approximately 36 hours to use the car as they wished. The experiences of Axsen et al. (2013) and Skippon and Garwood (2011) suggested that this would be long enough to enable participants to experience and understand the capabilities and limitations of BEVs, and to reflect on how BEVs might or might not fit with their lifestyles and vehicle usage patterns.

After the driving experience⁴³, participants returned the car to TRL, and were paid an incentive of £10 for their partial completion of the study to this point. Between two and three days later, they were emailed a link to the online post-experience questionnaire. Once that was completed they were paid a further £50 incentive for their participation.

Measures

Sample characterization: IPIP-NEO 120-item personality inventory

The IPIP-NEO 120-item personality inventory (Costa & McCrae, 1995; Goldberg, et al., 2006; McCrae & Costa, 2003) was used in the pre-experience questionnaire to measure participants' 5-factor personality traits (openness, conscientiousness, extraversion, agreeableness, and neuroticism). Responses to a sub-set of these items were used to calculate self-congruity (see below).

Dependent Measures: Evaluation of vehicle performance

The evaluation of vehicle performance part of the post-experience questionnaire contained 11 items measuring participant ratings of performance of the vehicle experienced, plus other aspects of the driving experience. The items covered those aspects of performance identified in Study 1 as the ways in which drivers construe vehicle performance: acceleration from 0-20mph, acceleration from

⁴³ A detailed examination of usage behaviour (based on onboard GPS data logging), as part of the wider study, showed that the experimental group had a narrower range of total travel distances, reflecting the range restrictions of the BEV. Also the experimental group's journeys on average took significantly longer than the control group journeys, but were of similar distances, suggesting that participants in the experimental group drove the electric car more slowly than the participants in the control group drove the diesel car.

30-50mph, smoothness of gear changes⁴⁴, responsiveness, power, smoothness and noise when cruising. Top speed was not included because the top speed of both vehicles in the experiment substantially exceeded the UK national speed limit, so asking drivers to evaluate it would not have been ethical. In addition, participants were asked to rate overall performance, and three other aspects of the driving experience: comfort, safety and enjoyment. The questionnaire used the Borg CR-10 Category-Ratio scale (Borg, 1998, p39).

Please rate the acceleration from 30mph to 50mph of the car you used in the experiment, by selecting one number from the scale provided and placing a tick in the white box under it												
None at all	Extremely low	Very low	Low	Moderate		High		Very High			Extremely high	Maximal
0	0.5	1	2	3	4	5	6	7	8	9	10	X

Table 11-2. Example of a self-report Borg CR-10 scale item measuring perceived acceleration from 30 to 50 mph during the experiment

This scale is claimed (Borg, 1998, p39) “to be able to describe a psychophysical stimulus-response function over a wide range of stimulus intensities with a mathematical function that as accurately as possible reflects the genuine growth of the sensory perception”, i.e. it is intended to reflect the form of mental “scales” of perceived stimulus intensity better than, say, Likert-type ordinal scales. The scale has a non-linear, positively accelerating growth function for perceived intensity, with verbal anchors ranging from “no (stimulus) at all” up to “extremely high” (the maximum the participant has ever experienced). There is also a final category, “maximal (stimulus)”, defined as the highest value of the stimulus that the participant could imagine experiencing. The scale was developed to measure perceived exertion and perceived pain, but has also been used previously for perception of vehicle performance attributes (perceived loudness of engine idle noise and perceived

⁴⁴ Driving the BEV did not involve changing gear, so this was expected to be rated highly by experimental group participants

intensity of steering wheel vibration; Ajovalasit & Giacomini, 2007). Table 11-2 shows an example of a Borg CR-10 scale item to measure perceived acceleration from 30 to 50 mph.

Dependent measures: Symbolic meaning and self-congruity

In both the pre-experience and post-experience questionnaires, participants' attributions of symbolic meaning to BEVs were measured using the attribution-vignette method (Chapter Nine). 18 items measured participants' attributions of personal characteristics to an imagined typical user of a BEV. The items were the same as those used in Studies 7, 8, and 9. Responses were compared with the norms recorded in Study 7 for the symbolic meanings of major classes of cars.

As in Studies 7, 8 and 9, ten of the items were used to measure participants' attributions of the five-factor personality traits (Costa & McCrae, 1995; McCrae & Costa, 2003) openness, conscientiousness, extraversion, agreeableness and neuroticism to an imagined typical user of a BEV. Responses to each personality item were compared with participants' own self-report responses⁴⁵ to the same items in the IPIP-NEO personality inventory, to calculate a measure of self-congruity:

$$SD_i = \frac{1}{N} (\sum_{n=1}^N |Att_{ni} - SR_{ni}|) \quad \dots(11-1)$$

Where SD_i is self-discongruity⁴⁶ for the i^{th} participant, N is the total number of personality items in the summation (10, two for each five-factor trait), Att_{ni} is the attribution made by the i^{th} participant

⁴⁵ As noted in Chapter Nine, the ten symbolic meaning personality items were selected from the IPIP-NEO inventory. However some of them were adjusted to have opposite valence than the equivalent IPIP-NEO item (see Chapter Nine). In the self-congruity analysis this valence change was corrected for before the self-congruity calculation.

⁴⁶ Other authors have described similar expressions to equation (11-1) as measures of self-congruity (e.g. Eriksen, 1996). However since SD_i decreases toward zero as self-congruity increases, it is better described as a measure of the opposite: self-discongruity. The transformation of equation (11-2) yields an appropriate measure of self-congruity.

in response to the n^{th} item, and SR_{ni} is the i^{th} participant's self-report in response to the same item in the IPIP-NEO part of the questionnaire. Since each Att_{ni} or SR_{ni} score could take a value from 1 to 5, this measure ranged from 0 (maximum self-congruity – the personality attributed to a typical user of a BEV exactly matched the participant's self-report of his/her own personality) to 4 (maximum self-discongruity – the personality attributed to a typical user of a BEV was as mismatched as possible to the participant's self-report of his/her own personality).

Self-discongruity was then converted to a normalised self-congruity score using the simple transformation:

$$SC_i = \frac{1}{4}(4 - SD_i) \quad \dots(11-2)$$

The normalised self-congruity SC_i measure ranged from 0 for maximum self-discongruity to 1 for maximum self-congruity.

Dependent measures: Willingness to consider a BEV as a main or second household car

In both the pre- and post-experience questionnaires, participants were asked to indicate (by selecting *yes* or *no*) whether they would consider owning an electric car as a main car in their household, if it had a range when fully charged of 50, 100, 150, 200 or 250 miles. These questions were repeated for ownership of an electric car as a second car in their household.

Results

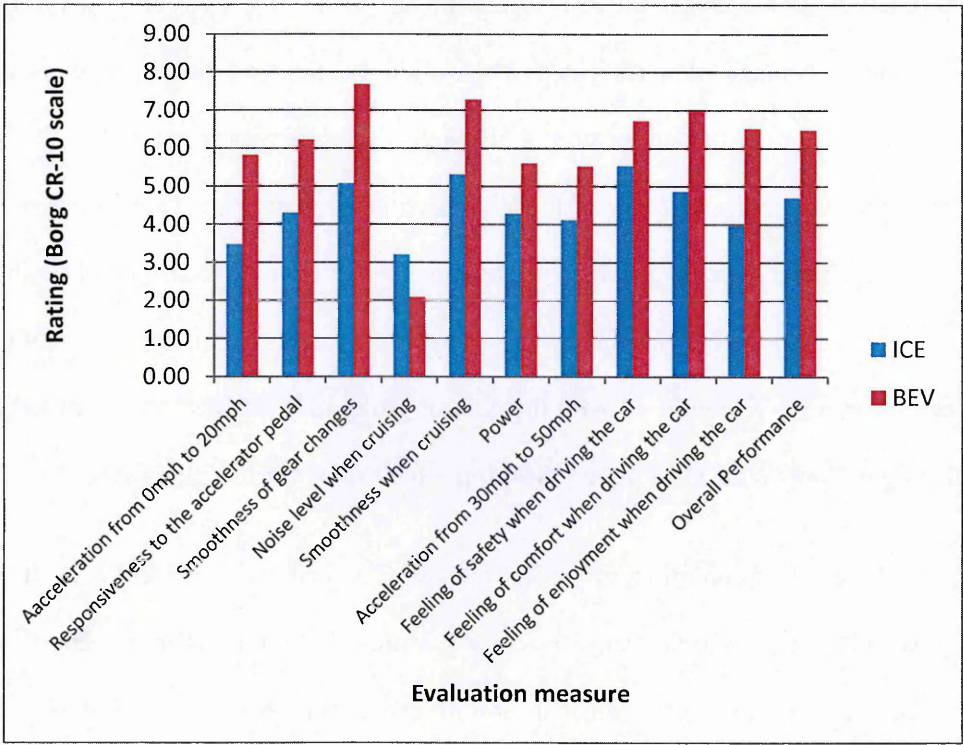
Evaluation of performance of BEV compared with ICE

Figure 11-1 shows how participants in the experimental group evaluated the performance of the BEV, and the experience of driving it, compared with the same data from the control group concerning their evaluations of the Ford Focus diesel control vehicle.

The pattern of results was particularly clear: the BEV was rated as having significantly better dynamic performance (acceleration from 0 to 20 mph ($t(391) = 8.804$, $p < 0.001$), (acceleration from 300 to 50 mph ($t(391) = 5.710$, $p < 0.001$), smoothness of gear changes ($t(391) = 8.269$, $p <$

0.001), responsiveness ($t(391) = 7.454, p < 0.001$), power ($t(391) = 8.804, p < 0.001$) and significantly better cruising performance (smoothness when cruising ($t(391) = 9.234, p < 0.001$), lower noise when cruising ($t(391) = -2.439, p = 0.015$)). Overall performance was also rated higher ($t(391) = 6.315, p < 0.001$).

The other aspects of the driving experience – feelings of comfort ($t(391) = 4.910, p < 0.001$), enjoyment ($t(391) = 8.423, p < 0.001$), and safety ($t(391) = 7.234, p < 0.001$), – were also rated higher for the BEV than for the ICE car.



Note: for Noise level when cruising (only), a higher value is a demerit (noisier)

Figure 11-1. Evaluations of performance and driving experience: BEV (Nissan Leaf) compared with conventional ICE car (Ford Focus diesel)

Regression analysis: prediction of overall performance from ratings of performance attributes

A regression analysis was conducted to test how far ratings of the seven individual performance attributes predicted the overall performance rating. An initial multiple regression indicated high collinearity between the variables, so a hierarchical regression was performed, entering variables in the order of their statistical significance in the original multiple regression. The best model fit was

obtained with only two variables retained, power and smoothness when cruising, with collinearity now reasonably low (tolerance = 0.784 for both variables). This model had an R^2 of 0.653, and the fit was highly significant ($F(2, 390) = 367.65, p < 0.001$). The model was:

$$Perf = 0.493 + (0.401 \times Smoothness) + (0.543 \times Power) \quad \dots(11-3)$$

Willingness to consider owning an electric car

Figure 11-2 shows the proportion of participants who would choose a BEV as their main household car, as a function of the range the car would travel on a fully charged battery. Before the experiment, the percentage of participants who would consider owning a BEV as their main household car was similar for both groups at all range values. It was very low for 50 miles range (the realistic extra-urban driving range of the BEV used in the experiment) but increased for higher ranges. At every range the percentage of participants who would consider choosing a BEV decreased after the experiment. The decrease was larger in all cases for the experimental group who experienced using a BEV, compared with the control group (the between-groups difference being statistically significant (Wald chi-square = 8.284, $p = 0.004$) for the 150 mile range⁴⁷).

Figure 11-3 shows the proportion of participants who would choose a BEV as their second household car, as a function of the range the car would travel on a fully charged battery. The broad patterns were the same as for a main car. Before the experiment, the percentage who would consider owning a BEV was approximately the same for both groups, starting very low for 50 miles range but increasing as the range increased. The percentage of participants responding positively decreased after the experiment, and for the lower three range categories the decrease was larger for the experimental group (the between-groups difference being statistically significant (Wald chi-square = 4.972, $p = 0.026$) for the 100 mile range, and almost so for the 50 mile range (Wald chi-square = 3.688, $p = 0.055$)).

⁴⁷ Statistical tests of the data in Figures 11-2 and 11-3 were by statistician Louise Lloyd of TRL Ltd.

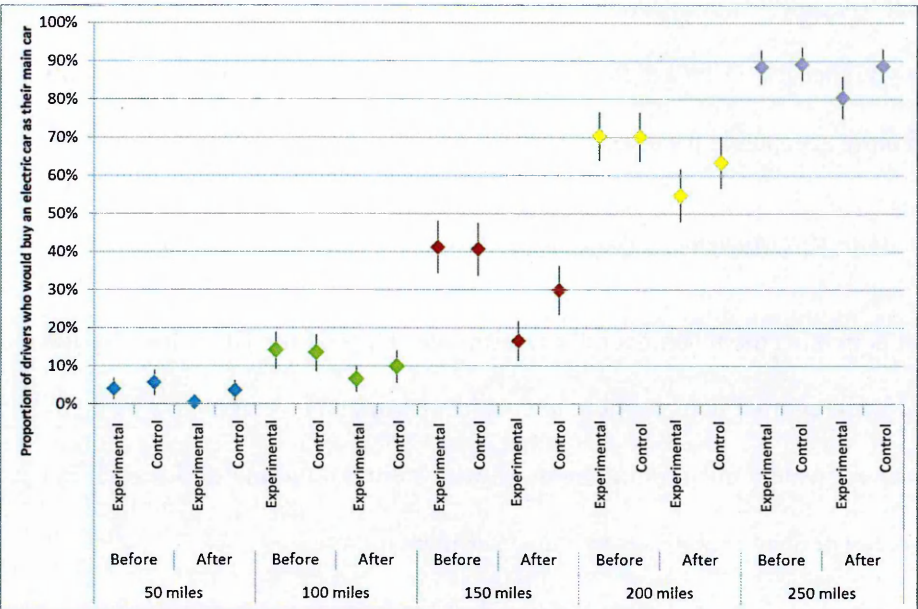


Figure 11-2. Percentage of participants who would consider owning an electric car as a main household car for various possible ranges on a fully charged battery, before and after experiment, in experimental and control groups

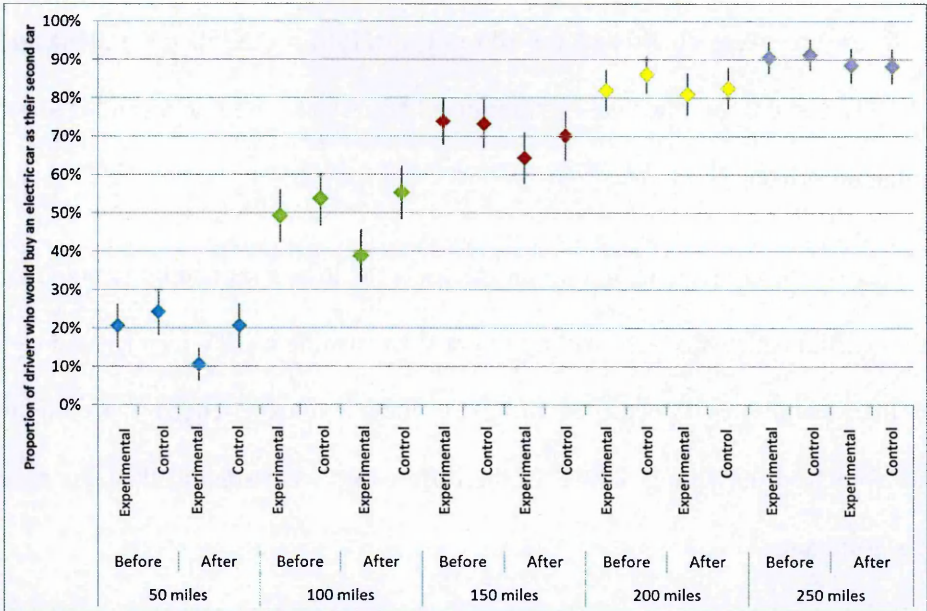


Figure 11-3. Percentage of participants who would consider owning an electric car as a second household car for various possible ranges on a fully charged battery, before and after experiment, in experimental and control groups

However the percentages who would consider choosing a BEV as a second household car were considerably higher for all ranges than they were for a main car, suggesting that lower ranges were considered more acceptable for a second car.

Does evaluation of performance predict willingness to consider owning a BEV?

Figure 11-4 compares the mean overall performance rating of the BEV they experienced, given by participants who reported being willing to consider owning an electric car as a main household car, alongside the equivalent mean rating by those who were not willing to, for each range. The data is based on post-experience responses by the experimental group.

Participants who were willing to consider owning a BEV as a main household car on average also rated the overall performance of the BEV they had experienced more highly than did participants who were unwilling to consider owning a BEV. This was especially so for those participants willing to consider a BEV as a main car even if its range was relatively low; the effect diminished as the potential range of the BEV increased (and more participants were willing to consider owning one). The differences were significant for 100 miles ($t(196) = 2.875$, $p = 0.004$) and 150 miles ($t(196) = 3.190$, $p = 0.002$). The “yes” rating for 50 miles was based on a single participant so a t -test was not appropriate.

Figure 11-5 shows the equivalent data for an electric vehicle as a second household car. Inspection suggests that participants who were willing to consider owning a BEV as a second car on average also rated the overall performance of the BEV they had experienced more highly than did participants who were unwilling. However the differences were smaller than for a main car and none were significant.

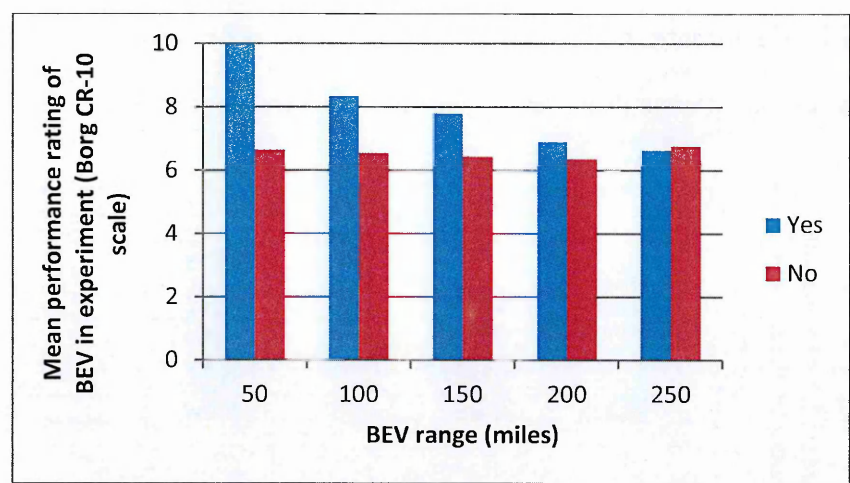


Figure 11-4. Mean performance rating of the BEV experienced in the experiment, for participants willing to consider (yes) and unwilling to consider (no) a BEV as a main car if its range on a full charge was 50, 100, 150, 200 or 250 miles

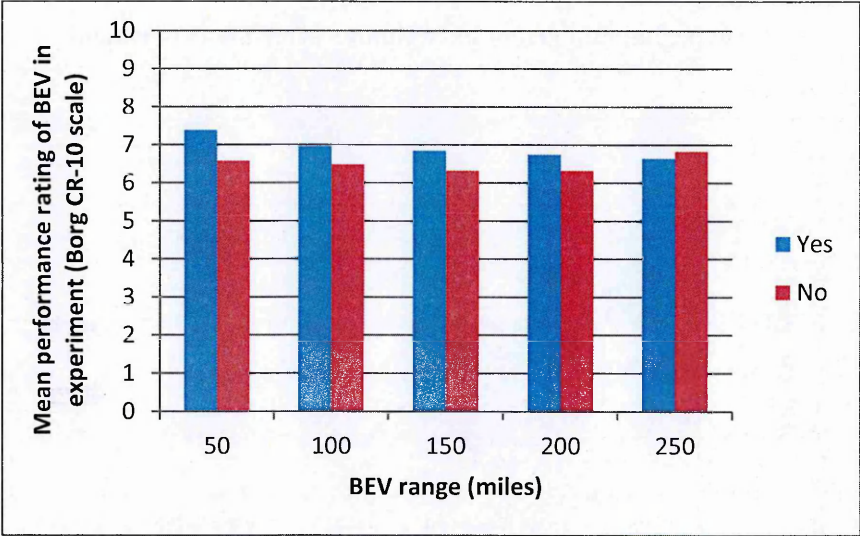


Figure 11-5. Mean performance rating of the BEV experienced in the experiment, for participants willing to consider (yes) and unwilling to consider (no) a BEV as a second car if its range on a full charge was 50, 100, 150, 200 or 250 miles

Symbolic meaning and self-congruity

Symbolic meaning of a BEV

Figures 11-6 and 11-7 show the symbolic meaning attributed to the BEV by the experimental group after the experiment. Figure 11-6 shows the personality traits attributed to a typical BEV user:

she/he would be significantly higher than average in the traits openness, conscientiousness, and agreeableness, and no different than average in extraversion and neuroticism.

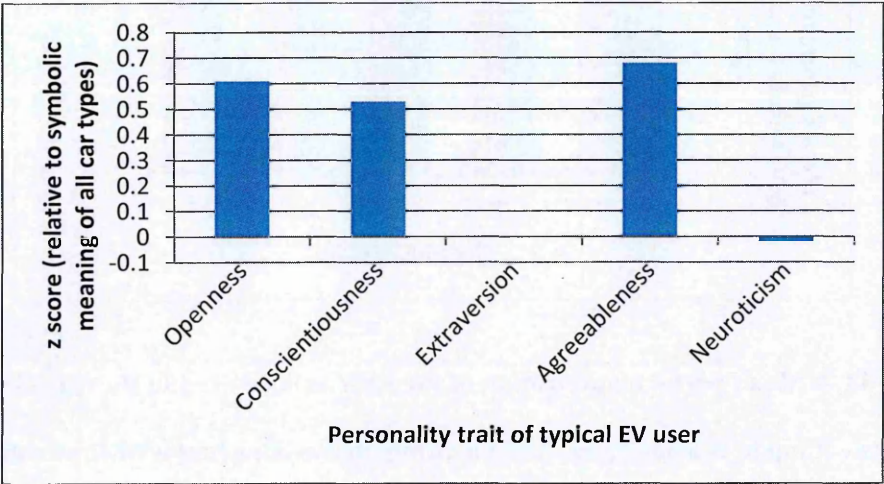


Figure 11-6. Symbolic meaning of a BEV: personality traits attributed to a typical BEV user by experimental group participants after the experiment

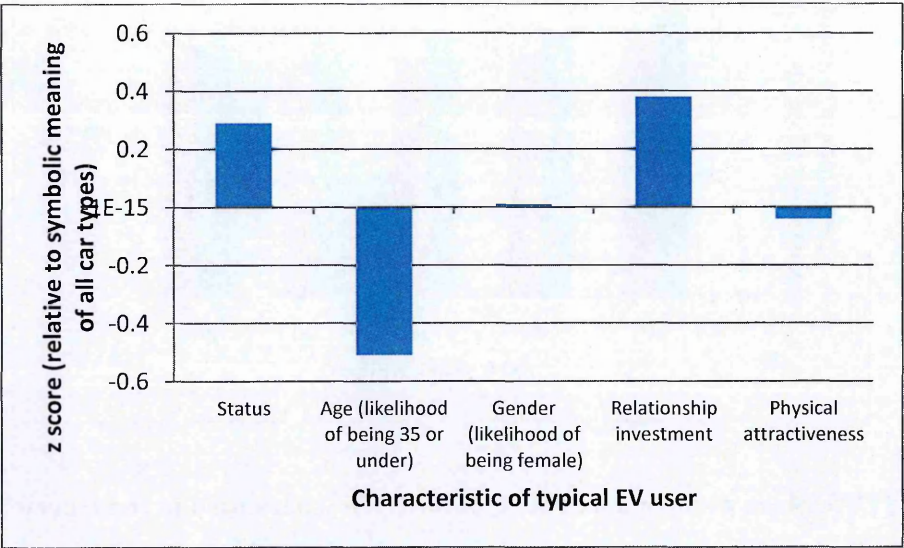


Figure 11-7. Symbolic meaning of a BEV: status, age, gender, relationship investment and physical attractiveness attributed to a typical BEV user by experimental group participants after the experiment

Figure 11-7 shows the status, age, gender, relationship investment and physical attractiveness attributed to a typical BEV user: he/she would be of higher than average status, more likely than average to have high relationship investment (i.e. to be in a stable relationship), and more likely to

be over 35 years old. His/her physical attractiveness would not be different from average and she/he would be no more likely to be female than male or vice-versa.

Figures 11-8 and 11-9 show the differences in the same attributions made by the experimental and control groups, before and after the experiment. A mixed factorial ANOVA was carried out for the five personality traits, with Trait and Time as within-participant factors and Group as a between-participant factor. The main effect of Trait was significant ($F(4,1564) = 225.393, p < 0.001$) as was the Trait \times Time interaction ($F(4,1564) = 10.870, p < 0.001$) but the effect of Group was not. Thus the patterns of attributions were similar for both groups, there were minor differences in attributions before and after the usage experience. Attributions of conscientiousness and agreeableness by both groups were slightly lower after the experience. Both groups attributed a slight introversion (negative z score on trait extraversion) before the usage experience, which reduced after the experience, substantially more so for the experimental group than the control group. Both groups attributed a slight neuroticism before the experience, which reduced to average for the experimental group after the experience, but remained the same for the control group.

A mixed factorial ANOVA was also carried out for the non-personality characteristics (age, gender, relationship stability, status, and physical attractiveness) with Characteristic and Time as within-participant factors and Group as a between-participant factor. The main effect of Characteristic was significant ($F(4,1564) = 462.278, p < 0.001$) as was the Characteristic \times Time interaction ($F(4,1564) = 2.559, p = 0.037$) but the effect of Group was not. Attributions of status rose after the usage experience, substantially more so for the experimental group. Attributions of age changed slightly after the experience, though in different directions for the two groups: likelihood of being younger fell for the control group but rose for the experimental group. Likelihood of being female also changed in different directions: decreasing for the control group and increasing for the experimental group. Before the experience, both groups considered that the typical user of a BEV would be somewhat less physically attractive than average. After the experience the attribution of the experimental group changed (to average attractiveness) while that of the control group remained the same.

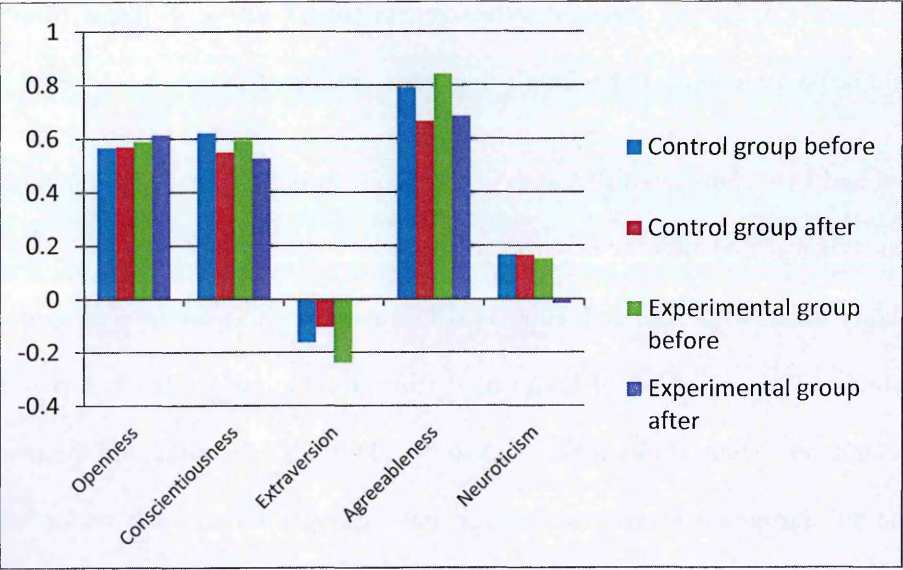


Figure 11-8. Symbolic meaning of a BEV: personality traits attributed to a typical BEV user by both groups, before and after the experiment

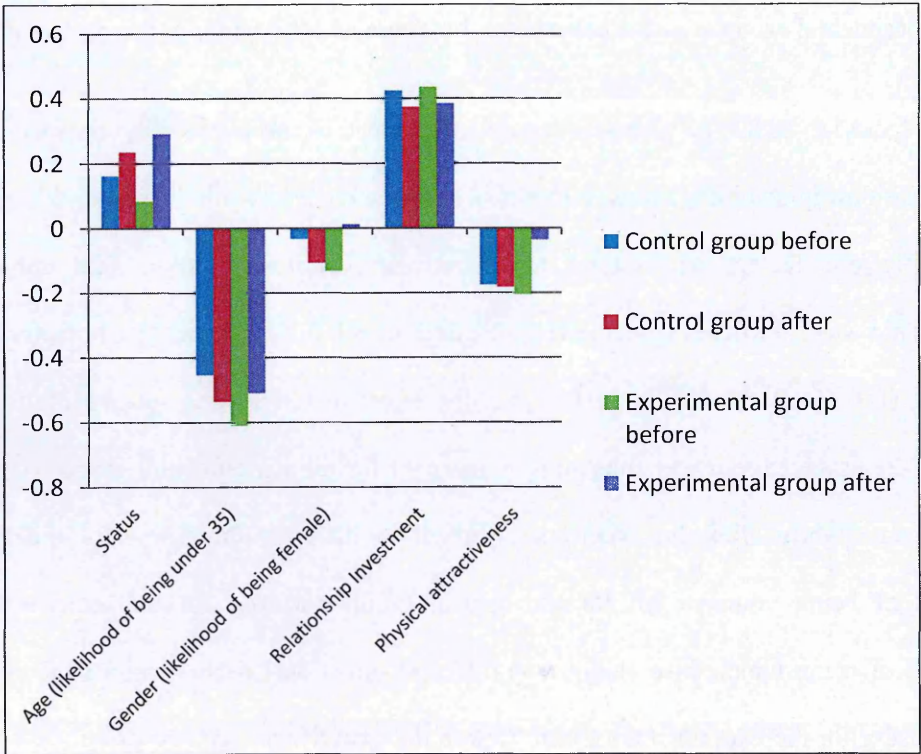


Figure 11-9. Symbolic meaning of a BEV: status, age, gender, relationship investment and physical attractiveness attributed to a typical BEV user by both groups, before after the experiment

Thus the data shows evidence of effects both from participation in the experiment (before-after changes in the control group) and from experience of the BEV (inter-group differences after the experiment). However both of these effects were rather small.

Self-congruity

Figure 11-10 compares the mean normalized self-congruity \widehat{SC}_{yes} of experimental group participants who responded “yes”, i.e. that they were willing to consider owning an electric car as a main household car, alongside the equivalent \widehat{SC}_{no} of those who were not willing to, for each range. The data is based on post-experience responses. \widehat{SC}_{yes} was higher than \widehat{SC}_{no} when the range was short, but the difference disappeared for ranges of 200 miles and above (the difference for 100 miles range was significant: (independent samples t-test, equal variances not assumed, $t(16.99) = 2.403$, $p = 0.028$; the “yes” data for 50 miles range came from a single participant).

Figure 11-11 shows the equivalent data for control group participants, which shows a similar pattern (the differences for 50 miles range $t(10.40) = 3.093$, $p = 0.01$ and 100 miles range $t(26.05) = 2.221$, $p = 0.035$) were significant; independent samples t-test, equal variances not assumed). The mean self-congruity of participants unwilling to consider owning a BEV, even if its range was 250 miles, was lower than at other ranges ($t(26.81) = 1.848$, $p = 0.076$).

Figures 11-12 and 11-13 show the data from both groups in relation to willingness to consider owning a BEV as a second household car. There was an overall tendency for \widehat{SC}_{yes} to be higher than \widehat{SC}_{no} , but none of the differences were significant, and the pattern of bigger differences for shorter BEV ranges seen in the responses for BEVs as main household cars was not repeated.

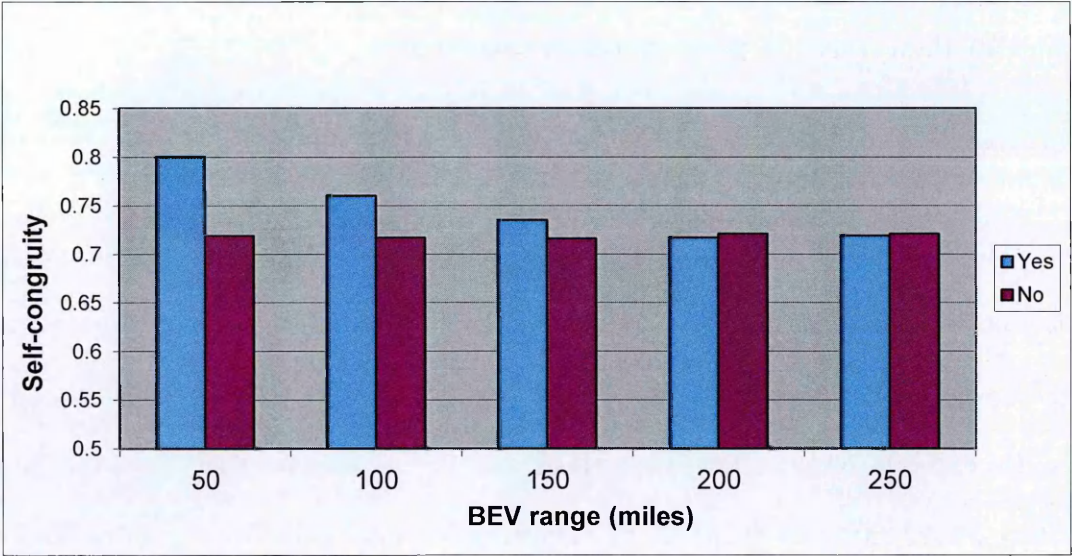


Figure 11-10. Mean normalized self-congruity of experimental group participants willing to consider (yes) and unwilling to consider (no) a BEV as a main car if its range on a full charge was 50, 100, 150, 200 or 250 miles (based on post-experience responses)

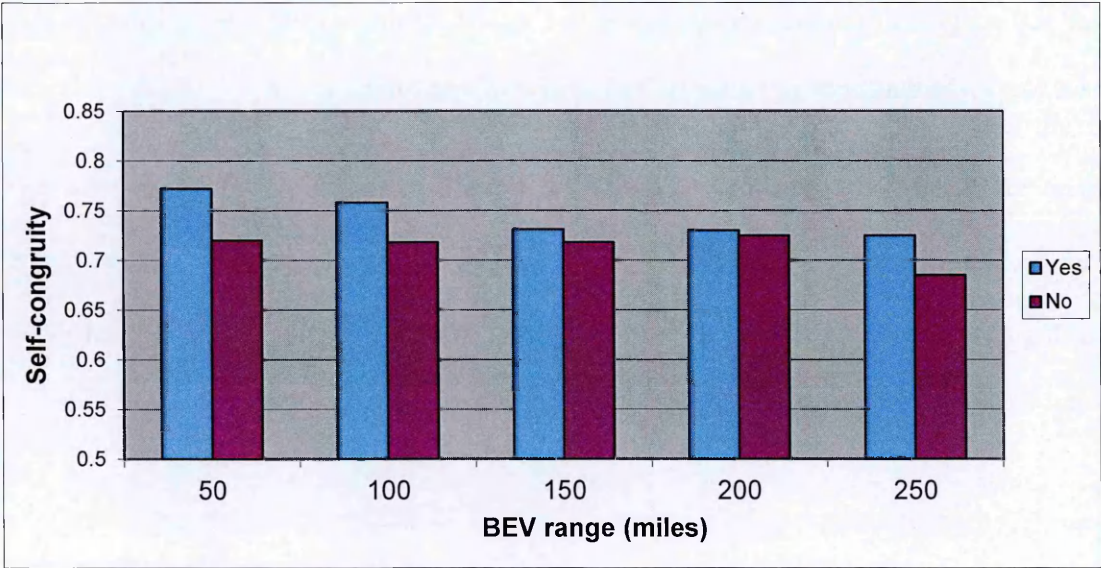


Figure 11-11. Mean normalized self-congruity of control group participants willing to consider (yes) and unwilling to consider (no) a BEV as a main car if its range on a full charge was 50, 100, 150, 200 or 250 miles (based on post-experience responses)

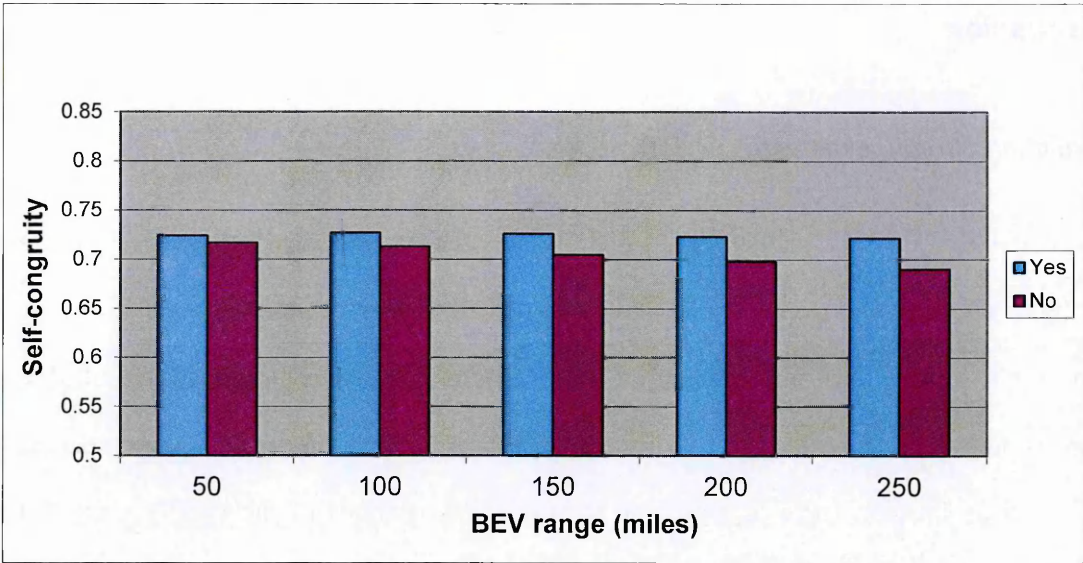


Figure 11-12. Mean normalized self-congruity of experimental group participants willing to consider (yes) and unwilling to consider (no) a BEV as a second household car if its range on a full charge was 50, 100, 150, 200 or 250 miles (based on post-experience responses)

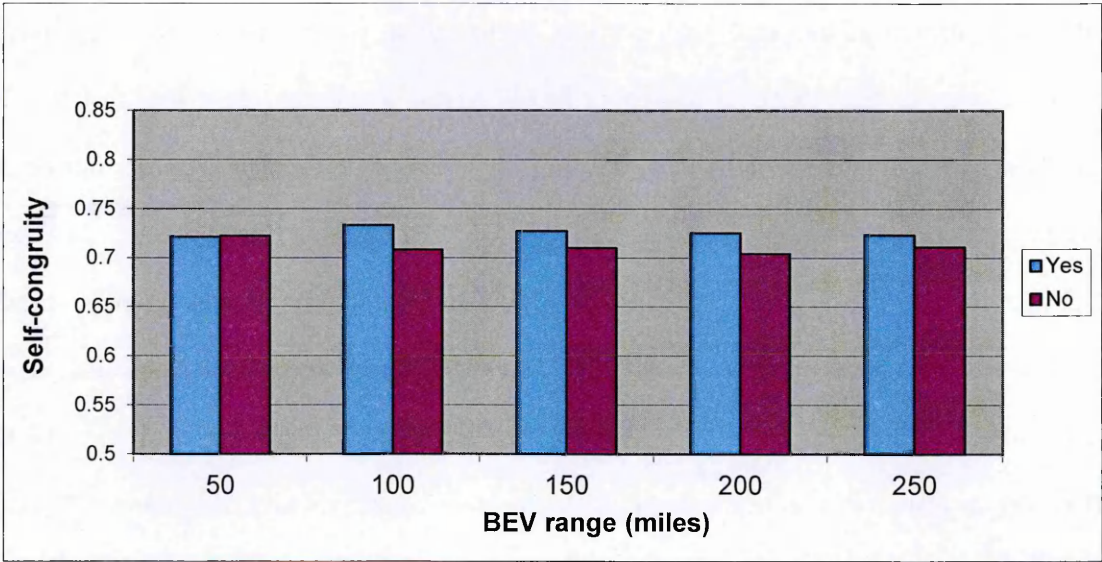


Figure 11-13. Mean normalized self-congruity of control group participants willing to consider (yes) and unwilling to consider (no) a BEV as a second household car if its range on a full charge was 50, 100, 150, 200 or 250 miles (based on post-experience responses)

Discussion

Prediction of ratings of overall performance

The regression analysis enabled a test of how far ratings of the seven individual performance attributes predicted the overall performance rating. The best-fit regression model contained only two terms, *Power* and *Smoothness*: one representing dynamic performance and the other representing cruising performance. This confirms that both of the dimensions of performance identified in Chapter Three are involved in drivers' evaluations of the "performance" of their vehicles, and that they have similar weights in those evaluations. There is, perhaps, an emphasis on dynamic performance alone in discourses on vehicles, so this finding merits consideration. Discourses frequently neglect cruising performance, yet these results suggest that it matters to drivers nearly as much as dynamic performance.

Perceptions of EV performance

Both the dynamic performance and cruising performance of the BEV were perceived as significantly better than those of the equivalent ICE car. It appears, therefore, that the 2012 generation of BEVs was a considerable advance, in terms of performance, on the immediately preceding generation of vehicles experienced by MMCD participants in earlier studies (Axsen et al., 2013; Graham-Rowe et al., 2012; Skippon & Garwood, 2011). The experiment therefore confirms that electric powertrains can now potentially offer performance advantages over equivalent ICE vehicles, in both the dimensions that are relevant to consumer drivers. The large differences in perceived acceleration ratings for the BEV compared with the control ICE vehicle suggest that dynamic performance advantages exceed the difference thresholds for perceived acceleration over different speed ranges measured in Chapter Six. Such benefits might potentially offset some of the disutilities of BEVs (short range, long recharge times, high costs), at least for some drivers.

It appears that those experimental group participants who were willing to consider owning a BEV also on average rated the performance of the BEV they had driven in the experiment higher than

did those who were unwilling to consider one. Since the objective performance of the BEV was the same for all participants, this suggests that those willing to consider owning a BEV either (a) have, on average, lower expectations of performance from vehicles, so their ratings for any vehicle are higher; (b) are favourably disposed towards BEVs in general, and this leads them to evaluate BEV performance more favourably. Since there was no significant effect among members of the control group (i.e. those willing to consider a BEV rating the performance of the control ICE vehicle higher than those unwilling to consider one), (b) is the more likely explanation.

Symbolic meaning of a BEV

The attribution-vignette method expresses the symbolic meaning of a product, product attribute or usage behaviour in terms of the five-factor personality and other traits of a typical user. The experiment found that a typical BEV user would be significantly higher than average in the five-factor traits openness, conscientiousness and agreeableness, and no different than average in extraversion and neuroticism. He/she would be of higher than average status, more likely than average to have high relationship investment, and more likely to be older than 35. There was internal consistency in these findings: agreeableness and relationship investment tend to be associated, while conscientiousness tends to increase with age (McCrae & Costa, 2003). Higher status is also generally associated with age.

That similar attributions were made by both groups, before and after the experiment, indicates that these symbolic meanings did not depend on the experience of using a BEV, but rather, were meanings shared within the UK car-using culture of which the participants were members.

The personality trait findings were in close agreement with those of Skippon and Garwood (2011) using an earlier version of the attribution-vignette method with a different sample. They were also quite consistent with the findings of Heffner et al. (2007) who studied symbolism in California's early market for HEVs, using the entirely different method of analysis of owners' qualitative narratives. They found that the meanings signified by HEVs included concern for others (related to agreeableness), maturity/sensibility (related to conscientiousness), and individuality in the embracing of new technology (related to openness). Schuitema et al. (2013) found that "pro-

environmental identity” predicted favourable attitudes towards EVs, while “car authority identity” did not; meanwhile Axsen and Kurani (2012) and Axsen et al. (2013) suggested that aspects of lifestyle related to identity (such as “liminal” lifestyles⁴⁸) could influence willingness to consider EVs. Experiment 13 did not directly measure whether these particular aspects of identity are symbolized by BEVs. In Miller’s (2009) theory of symbolic meaning (Chapter Eight), such meanings are hierarchically subordinate to five-factor personality traits (for instance, pro-environmental identity is associated with agreeableness, liminality with openness), so I set out only to measure most general meanings. However the attribution-vignette method could be readily adapted to measure such subordinate meanings too.

Comparing the findings with Study 7 (Chapter Nine), the vehicle categories to which a BEV is (at present) closest in symbolic meaning are family hatchbacks and MPVs (and, to a somewhat lesser extent, small hatchbacks). The comparisons are not, of course, exact: for instance the typical user of a BEV would be higher in status than the typical user of any of these categories. Broadly, the typical user of a BEV would be similar to the typical user of a family hatchback or MPV, but higher in status (perhaps necessary to afford the higher purchase cost) and higher in openness (perhaps reflecting the relative novelty of BEVs).

Comparing the findings with those of Study 9 (Chapter Nine), the symbolic meaning of BEV is quite similar to the symbolic meanings associated with good cruising performance (smoothness and quietness when cruising), but quite different from the meanings associated with dynamic performance. Thus while the modern BEV used in Experiment 13 had *both* higher cruising performance and higher dynamic performance than an equivalent ICE car, the symbolic meaning of a BEV is consistent only with the symbolism of good cruising performance; it is inconsistent with that of good dynamic performance. It follows that whilst a BEV might be experienced as having good dynamic performance, it would not fulfil the same symbolic goals as conventional cars with

⁴⁸ “Liminal” refers to lifestyles that are undergoing, or are in some sense ready for, substantial change

high dynamic performance. Perhaps this is a result of culturally shared perceptions of the dynamic performance of BEVs lagging behind the reality of the present capabilities of the vehicles.

Self-congruity and BEV uptake

Experiment 13 suggests that self-congruity is a factor in willingness to consider owning a BEV as a main car which has a short range (50 or 100 miles – the typical ranges on a fully charged battery of BEVs available on the market at the time of writing, depending on type of driving). Participants willing to consider these vehicles tended to have higher self-congruity with the symbolic meanings of BEVs than those who were unwilling to consider them. I note, however, that rather few participants were willing to consider a BEV with short range as a main car at all. Thus the small number who were willing to consider owning a BEV as a main car despite the limitations of short range were also those most self-congruent with the symbolic meanings of BEVs; as predicted by self-congruity theory.

The effect disappeared for BEVs with longer ranges (≥ 200 miles). I speculate that the utility of shorter-range BEVs is low for drivers' instrumental goals, low for the symbolic goals of non-self-congruent drivers, and high for the symbolic goals of self-congruent drivers. Therefore their appeal is likely to be restricted to self-congruent people for whom symbolic goals also happen to outweigh instrumental goals in relative importance. The utility of longer-range BEVs for drivers' instrumental goals is higher, so for self-congruent drivers, their symbolic goals and instrumental goals may be simultaneously met by using a BEV. Less self-congruent drivers for whom instrumental goals outweigh symbolic goals may also find BEVs appealing.

Of course, we should not expect the symbolic meanings of BEVs to remain constant. Both the purchase cost and novelty of BEVs could change over coming decades, so their capacity to act as costly signals of status and openness may reduce. Nevertheless to the extent that self-congruity influences purchase decisions, people with the kind of profile found in Experiment 13 are likely to form the early-market target audience.

Implications for the uptake of BEVs, PHEVs and E-REVs

People who have driven a modern BEV respond very positively to the driving experience, including the BEV's performance in both dimensions⁴⁹. However that response is not enough to outweigh the instrumental disutilities of a BEV (high cost, long recharge times, short range), except for the small number of people for whom self-congruity is high, and for whom fulfilment of their symbolic goals outweighs fulfilment of their instrumental goals⁵⁰. Thus "early adopters" will be people who are high in openness, conscientiousness and agreeableness, and higher than average in status, age and relationship stability.

Others will not consider a BEV until ranges can be substantially improved; but if they can, then the better performance (in both dimensions) and driving experience may then confer greater appeal to a wider audience relative to ICE vehicles. In addition, if BEVs then penetrate the market in larger numbers, their symbolic meanings may change in ways that widen the target audience further.

Although Experiment 13 was restricted to BEVs, it is also possible to draw some useful inferences concerning uptake of PHEVs and E-REVs. Firstly, drivers of E-REVs will be able to experience similar performance benefits to drivers of BEVs, as E-REVs are driven under electric power at all times, even when the range extender ICE is operating to provide the electricity for the motor. However, E-REVs do not suffer the key disutilities of short range and extended down-time to recharge the battery⁵¹. From this perspective an E-REV might look like an attractive vehicle to

⁴⁹ I assume here that responses to the one model of BEV used in Experiment 13 can be generalised to responses to most modern BEVs. The validity of this assumption is an empirical question for future research.

⁵⁰ or the few whose instrumental goals can be met by a very short-range vehicle

⁵¹ The battery of an E-REV is typically smaller than that of a BEV and so can be fully recharged in a shorter time; and of course an E-REV can be driven with a fully discharged battery, so it is available for use, like an ICE car, whenever there is liquid fuel in the tank.

many drivers, as either a main or second car, and be especially appealing for those who are self-congruent with its symbolic meanings.

The situation is more complex for PHEVs, because of the parallel configuration of their ICE and electric powertrains. A PHEV may drive under electric power at low speeds, ICE power in high speed cruising, and in blended mode, with both powertrains contributing, at intermediate speeds and during acceleration transients or under high loads such as during hill climbs. Thus PHEV drivers will not experience the cruising performance benefits of an electric drive, nor will they experience the full set of dynamic performance benefits, because accelerations will tend to be made in blended mode – but they potentially could still experience some, such as responsiveness and acceleration from standing start.

Experiment 13 did not measure the symbolic meaning of PHEVs and E-REVs, and speculation is perhaps risky. However a starting point might be to assume it is reasonably similar to that of BEVs, but the unrestricted range, and higher CO₂ emissions might both contribute to different symbolic meanings, with a less pro-environmental flavour. Thus the issue of the discongruity between the symbolic meaning of dynamic performance benefits and the symbolic meanings of the vehicles may affect PHEVs and E-REVs to a lesser extent, or not at all.

Both E-REVs and PHEVs will continue to be more expensive to purchase than conventional ICE vehicles (Energy Technologies Institute, 2013). Potential buyers will need to trade this off against potential running cost savings and lower CO₂ emissions (when the latter is a motivator). The performance and symbolic benefits discussed above can now be added to this trade-off. In general, E-REVs are likely to be more expensive to buy, but offer greater running cost savings, lower emissions, better cruising performance, better dynamic performance, and a more distinctive symbolic meaning than PHEVs. In Axsen and Kurani's (2013) survey study in California, participants tended to prefer cheaper PHEVs with smaller batteries to more expensive PHEVs with larger batteries; but their participants had not been specifically given the use of PHEVs or E-REVs; participants were unaware of the performance benefits I suggest here; and E-REVs were not distinguished from larger-battery PHEVs. How consumer choices will actually be distributed

across the PHEV and E-REV design space remains a matter for empirical study as these types enter markets.

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Chapter Twelve. Summary and conclusions

The overall aim behind this thesis was to provide a comprehensive picture of vehicle performance as understood and experienced by consumer drivers, to inform the future design of EVs and fuels for PHEVs and E-REVs.

Mass-market consumer drivers have tended to see the short range of BEVs on a single battery charge, and the extended down-time while recharging, as significant barriers to uptake. PHEVs and E-REVs do not have these disadvantages, but the need for two powertrains in the same vehicle means that they will continue to carry a cost premium over conventional ICE vehicles. To displace a significant fraction of ICE vehicles from the global vehicle parc, all three types will need to offer consumer drivers advantages over conventional ICE vehicles that offset these disadvantages. I have therefore explored the potential for them to offer advantages in terms of performance.

To do this I have addressed three research questions:

1. What does vehicle performance mean to consumer drivers, and what aspects of it matter most to them?
2. What influences consumer drivers' perceptions of those aspects of performance, in normal driving? What differences in those aspects can consumer drivers perceive?
3. How do consumer drivers value those aspects of performance?

In the three sections that follow I shall summarise the main conclusions from this research in relation to each question in turn. In each section I shall consider the key findings that represent original contributions to the field, further research that would be valuable as a follow-on to the findings, and a critique of the methodologies used. I shall then comment briefly on the importance of non-conscious mental processes in the research findings, and conclude by reviewing the implications of all of the above for the potential uptake of electric vehicles.

What does vehicle performance mean to consumer drivers, and what aspects of it matter most to them?

Key findings

I began by exploring how drivers themselves construe vehicle performance. The main finding was that they construe performance as having eight significant aspects: acceleration from standing start, mid-range acceleration, responsiveness to the accelerator pedal, power, smoothness of gear changes, top speed, smoothness when cruising, and quietness when cruising. Cluster analysis showed that these group into two overarching dimensions, that I termed *dynamic performance* (which included the first six aspects in the list) and *cruising performance* (which included the last two aspects in the list). In dynamic performance the driver is actively engaged in changing the state of motion of the vehicle, using the accelerator, while in cruising performance the driver is maintaining the state of motion of the vehicle, keeping the accelerator position approximately constant. Users of diesel fuelled cars appeared to place relatively more importance on cruising performance than did users of gasoline fuelled cars. This is a new and rather different understanding of how drivers construe performance than is apparent either in the research literature or in public discourse on vehicle performance, both of which have tended to emphasise only dynamic performance.

The study also found that the various attributes of dynamic and cruising performance are not construed in the abstract, but rather as relating to specific driving situations. Thus acceleration is construed in relation to situations such as pulling away, getting into gaps in traffic, or overtaking; while responsiveness is construed particularly in relation to getting into gaps in traffic. Power is frequently used as a synonym for acceleration, but it is also construed as having a particular meaning in relation to the ability to maintain speed on steep or long hills.

Possible further research

The model of how consumer drivers construe vehicle performance was based on responses from a U.K. sample. However there can be quite considerable differences in available vehicle types and

driving environments between countries, and cross-cultural differences in attitudes to driving and driving behaviours (Golias and Karlaftis, 2002; Ozkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006). These might impact, if not on the overall structure of the model, at least on the relative importance of dynamic and cruising performance and their more specific attributes. Study 3 might therefore usefully be repeated in other countries to refine the model and extend its range of validity.

Methodology

The repertory grid method provided a structured approach to eliciting how drivers construe vehicle performance, which could provide insight into relationships between constructs through the ability to use cluster analysis. General qualitative elicitation techniques such as focus group discussion, semi-structured interviews, or projective methods (Birn, 2002, Gordon & Langmaid, 1988)) do not offer this kind of analysis. The novel approach of developing grids as a collective endeavour by triads of participants, discussing and negotiating the meaning of each construct, appeared to succeed as a means of eliciting construct definitions that represented common understandings rather than idiosyncratic individual constructs. Repertory grids are used in other fields, including ergonomics, but their use in transport research is very rare. This research suggests that the method might be used more widely.

What influences drivers' perceptions of those aspects of performance, in normal driving? What differences in those aspects can consumer drivers perceive?

My focus in relation to the second research question has been on dynamic performance, and particularly on acceleration, because EV designers will need to trade off the magnitude of dynamic performance benefits against other needs for the limited capacity of onboard batteries, especially electric range.

Theory development

Individual differences in driving behaviour will have a significant impact on the actual accelerations drivers experience, and the opportunity afforded for them to experience the maximum dynamic performance available from a vehicle, so to fully understand how far drivers are able to perceive differences in vehicle performance, we need also to understand what influences driver behaviour. An important strand in modern social psychology explains human behaviour in terms of the simultaneous pursuit of multiple goals, each regulated in its own feedback control loop. Fuller's (2011) Risk Allostasis Theory of driving behaviour is based on feedback control, and Summala's (2000; 2007) Multiple Comfort Zone Model is a model of multiple goal pursuit. However neither these, nor other models of driving behaviour, have reflected the full diversity of goals that drivers may be pursuing when driving, including symbolic goals. Nor have they specified the mechanisms of inter-goal dynamics that ultimately determine behaviour, or the role of perception in feedback control. It was therefore necessary to develop a new inter-goal dynamics theory of driver behaviour (the IGD-driving model) that specifies mechanisms, and the role of perception, in more detail. In the IGD-driving model, both the reference values for goals, and their relative activation states, are determined as weighted sums of inputs from other goals in a hierarchical organization. Goal activation also depends on perception of the state of the world – i.e. the situation presented to the driver. This model provides a general account of how both dispositional and situational factors influence driving behaviour.

A new model was also developed for the perception of acceleration in naturalistic driving, using the IGD-driving model to reflect influences on driving behaviour that in turn influence the opportunities afforded during a drive for the driver to perceive the vehicle's acceleration. This model also incorporated a Bayesian statistical approach to the perception of acceleration, allowing for the combination of multiple perceptual cues contained in visual and auditory modalities, and prior knowledge of the likelihood of experiencing different acceleration rates, stored in memory.

Key empirical findings

Various aspects of the IGD-driving model and the perception model were tested in a driving simulation experiment, in which both driver behaviour and drivers' self-reports of perceived acceleration and responsiveness were measured while the available acceleration and responsiveness of the simulated vehicle, and the goals being pursued during driving were varied. I concluded that (1) drivers can perceive differences in aspects of dynamic performance during naturalistic driving, but only if these differences are relatively coarse; (2) differences in the performance of a vehicle lead to differences in driving behaviour, illustrating feedback control; (3) driving behaviour changes in response to the goals that are active in drivers' minds; (4) more dynamic driving behaviours afford more opportunity to perceive differences in vehicle performance; (5) more dynamic driving styles are associated with drivers who have the personality traits of low agreeableness, low conscientiousness and high neuroticism. Thus substantial differences in the dynamic performance available from a vehicle can be directly perceived by drivers in naturalistic driving, but more subtle differences cannot. The chances of a difference being perceived are greater when the driver is engaged in more dynamic driving behaviour; either because he/she has goals active whose pursuit involves fast, dynamic driving; or simply when the driver has certain personality traits that dispose him/her towards dynamic driving.

Perceptual difference thresholds for acceleration were measured in a series of paired comparison experiments in which the effects of driving behaviour were controlled for. An initial experiment testing the effect of combining cues from different sensory modalities showed that the driving simulator did not have absolute validity for the measurement of perceptual difference thresholds. It was therefore used only to determine the relative magnitudes of the difference thresholds for different initial speed and gear conditions, finding that the difference threshold was lower for mid-range accelerations (30-50mph) than for either accelerations from standing start (0-20mph) or accelerations from cruising speeds (50-70mph). The absolute difference threshold (DL_{75}) for mid-range accelerations was then found, in a paired comparison experiment using a real vehicle on a test track, to be 0.8 ms^{-2} , or 7.7%. This sets a lower limit on the mid-range acceleration benefit a designer needs to offer in order to ensure that a substantial majority of drivers can perceive that it is

better than that of a conventional car. A higher benefit is necessary for standing start accelerations, because drivers appear less able to distinguish acceleration rates in those conditions; however this is precisely the condition where acceleration benefits can most readily be offered by electric powertrains.

A more subtle picture emerged, however, from a further simulator experiment that showed that experiencing differences in the actual performance of a vehicle can lead to differences in overtaking behaviour, even if the differences in performance are below the perceptual difference threshold. This suggests that differences in a vehicle's performance can be learnt implicitly, through experience, leading to changes in the driver's mental model of performance, without the driver necessarily being consciously aware that this is happening. I suggested that these behaviour changes, or affective responses to them, might be perceived by drivers even when they cannot perceive the actual performance difference. This potentially gives the designer of a BEV more room to manoeuvre in making the trade-off between performance and range than the perceptual difference threshold alone might suggest. A BEV with an acceleration benefit (compared with an equivalent ICE car) that is below the perceptual difference threshold may still feel more "fun to drive" to a driver able to experience driving it for long enough to have implicitly learnt its performance, and used that learning in driving it. This research suggested that some such learning had taken place after less than 30 minutes of driving.

Possible further research

First, while Experiment 2 provided some initial tests of the IGD-driving model, there is considerable scope for further testing. Further experiments could, for instance, explore the effects of inter-goal dynamics on driving behaviour, by activating multiple goals and varying their relative activation levels. Such experiments could use a combination of explicit goal activation (via instructions to participants) and implicit goal activation (using the kinds of implicit goal activation paradigms that have been developed in experimental social psychology (Bargh & Chartrand, 2000; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Custers, Eitam, & Bargh, 2012)). It would be particularly interesting to develop ways to test the weighted-sum mechanisms proposed for the determination of reference levels for Task goals, or choices between alternative behaviours.

For instance, the individual reference level output by a particular Activity goal might be determined by measuring some quantifiable aspect of behaviour (such as speed or headway) in a paradigm that strongly activates that goal, for instance with instructions or incentives to prioritise it above all other considerations. Subsequently several competing or complementary Activity goals whose output reference levels had been measured could be activated simultaneously, and the same behaviour measured to see how far it is predicted by the weighted-sum model.

Second, another area for further research is how cues are combined in perception when driving. The Bayesian model of cue combination seems to offer considerable promise and driving simulation offers a particularly effective medium for designing ecologically valid but highly controlled experiments, both across sensory modalities and using multiple cues in the same modality.

Third, the difference thresholds measured in this research might not apply in all driving situations. For instance, drivers might be able to discriminate smaller differences in denser urban traffic where there are many more visual cues available. It would be difficult to do this in a controlled way on a test track, but straightforward in a driving simulator. Thus simulator studies could investigate the relative change in difference threshold in a dense urban environment compared with the less dense environment of Experiments 3 and 4.

Fourth, Experiment 6 provided preliminary evidence for a process of implicit learning of vehicle performance while driving. There is scope to extend this further, for instance by identifying more specifically what aspects of driving contribute most to the learning process, and how fast the process occurs. Implicit learning may also be a feature of other aspects of driving, such as anticipation of other drivers' behaviours, and this also merits investigation.

Methodology

This research has shown both the limitations and the strengths and of driving simulation as a research tool. Well-designed driving simulation experiments often exhibit *behavioural* validity, but perception is critically dependent on sensory cues available in the environment, and Experiments 3, 4 and 5 showed that the fidelity of cueing was insufficient to make absolute measurements of

perceptual difference thresholds. This reinforces the view that researchers need to consider fidelity and validity issues carefully in designing appropriate driving simulation experiments: where *perceptual* validity is required, simulator studies are likely to provide it only in a relative sense.

On the other hand, driving simulation provides a uniquely immersive virtual reality environment that enables highly controlled and reproducible experimental situations that also have high ecological (external) validity. This combination of high external and internal validity is rare in psychological research: the traditional paradigm of laboratory experiment has high internal validity but low external validity, and vice-versa for the alternative of field studies. This suggests that driving simulation might provide a way to test modern social psychological theories of goal-directed behaviour, and cognitive theories of perception and learning, with much greater external validity than traditional laboratory-based approaches.

How do consumer drivers value those aspects of performance?

Key findings

Vehicle performance benefits can only help to offset the various disadvantages of EV types (short range and long recharge times for BEVs, higher purchase cost for all three types) to the extent that drivers attach value to such benefits.

Vehicle performance clearly has some instrumental benefits. As we have seen, for example, drivers make more frequent positive decisions to overtake when driving a higher-performance vehicle, and in principle this may reduce the length of some journeys, helping to fulfil the journey goal *get to destination as quickly as possible* in the IGD-driving model. Likewise, high responsiveness may enable a driver more easily to move out into gaps in busy urban traffic, again helping to fulfil the journey goal to get to destination as quickly as possible.

However consumers acquire and use material goods in the pursuit of symbolic as well as instrumental goals. Symbolic goals concern signalling something about the owner/user to other people, such as personal identity, status, or social category membership. Possession or use of material goods conveys such signals because goods carry symbolic meaning. It is this symbolic

meaning that gives goods symbolic value: their value in the pursuit of symbolic goals. While the instrumental value of vehicle performance is well understood, and the ways it is traded off versus other instrumental attributes of vehicles can be measured in discrete choice experiments, the symbolic value of vehicle performance has hardly been studied.

The lack of a consistent way to characterize and compare symbolic meanings has been a significant barrier to research in this area. I developed a novel attribution-vignette method to characterize symbolic meaning based on Miller's (2009) theory, in which the symbolic meaning of a product reflects the five-factor personality traits of its owner/user. In a series of studies, application of this method provided the first quantitative picture of the symbolic meanings of cars and vans, driving, and aspects of vehicle performance. The results showed that all of these have a rich set of meanings, widely understood and shared by members of the society in which they are used. They thus act as a symbol system that users can draw on in the pursuit of their symbolic goals.

Aspects of dynamic performance act as signals of the five-factor personality traits of low agreeableness and low conscientiousness, together with other mating-salient traits such as masculinity, youth, and low relationship investment. These meanings are consistent with the symbolic meanings of certain categories of cars, such as sports cars, and of more dynamic driving styles (risky, angry, high velocity). At the same time, cruising performance, particularly quietness when cruising, signals high agreeableness, high conscientiousness, and mating-salient traits such as being older, and high relationship investment, consistent with the symbolic meanings of other categories of cars such as MPVs (people carriers), and patient and cautious driving styles.

A second set of experiments using an entirely different method, based on implicit priming, confirmed these meanings with a reasonable degree of agreement. This supported the suggestion that the symbolic meanings identified represent genuine concept-trait associations stored in memory.

Possible further research

The attribution-vignette and implicit priming methods of Chapters Nine and Ten for the first time enable the quantitative measurement of the symbolic meanings of products and their attributes, and

of behaviours. They are supported by well-established theory and represent a major step forward from previous qualitative methods. Further, the quantitative nature of the methods enables them to be used to track the evolution of symbolic meaning with time (for instance, how quickly does an innovative product cease to signal high openness as it penetrates the market?) and to measure the effectiveness of interventions aimed at changing the symbolic meanings of products and behaviours.

There are potential applications in consumer psychology and marketing research, across product categories such as clothing, food and drink, mobile devices, and housing; and in other fields where symbolic goals may be relevant, such as health and environmental psychology. In transport research, some obvious applications would be to characterise and compare the symbolic meanings of car brands and powertrain types, and of alternative transport modes such as trains, buses, cycling, etc.

Methodology

The attribution-vignette method is simple to apply. It could be used in a postal survey, but an online survey provides for a more robust design, with randomisation of item order, when the sample bias inherent in online access is acceptable. In Studies 7, 8, and 9 I made the assumption that the range of vehicle classes, performance attributes and driving styles included represented the whole culturally available symbol set, so individual symbolic meanings could be normed against the distribution of meanings within the data set itself. However it is easy to envisage situations where it would be desirable to characterise the symbolic meaning of a product, product attribute, or usage behaviour without the need to measure the meanings of a comprehensive range of other products or behaviours against which to compare it. I have suggested that this might be done by establishing appropriate norms for the personality and other items used in the measurement, for the population in which meanings are to be measured.

The method can readily be adapted to include measures of more specific symbolic meanings, such as “pro-environmental” or “car authority” (Schuitema et al, 2013). Such meanings are seen in Miller’s (2009) costly signalling theory as hierarchically subordinate to personality traits, and these

hierarchical relationships could be investigated if they were measured together, for instance using structural equation modelling.

The implicit priming methods are much more complex and time-consuming to apply, and appear to generate weaker measures, but they are potentially useful when there is reason to be concerned about the risk of impression management in responses to the attribution-vignette method. In the first instance, replication of the method in another product category (such as clothing) or behavioural field (such as health/diet related behaviours) would be valuable.

The role of non-conscious processes

A recurring theme in these studies has been the importance of non-conscious mental processes. Since Freud (1915) elaborated his theory of the role of the unconscious in determining behaviour, modern social psychology has developed a picture in which automaticity – non-conscious control – plays a significant, even a dominant role in some forms of learning (Reber, 1993; French & Cleeremans, 2002) and determining human behaviour (Bargh, 1997; 2007). A new synthesis has emerged in which behaviour is influenced by goals that are activated, but outside conscious awareness (Bargh, 2007; Hassin, Uleman & Bargh, 2005).

In this work I have found evidence for non-conscious feedback control, in which differences in available vehicle performance affected drivers' use of the vehicle's controls, although those differences were too small to be verbally reported. I have also found evidence that implicit learning of vehicle performance affects drivers' decision making, in a situation where the behavioural difference could not be the result of direct perception of that performance. Both these strands of evidence are consistent with the new synthesis mentioned above, and the IGD-driving model that I developed is agnostic as to whether a person is or is not consciously aware of pursuing any particular goal that may be influencing their behaviour.

One class of goals that I have suggested have a considerable impact on driving behaviour (and hence on the opportunities afforded to perceive differences in vehicle performance) is symbolic goals. These are those goals that concern signalling something about oneself to others, or to

oneself. I have suggested that the influence of symbolic goals on driving behaviour is likely to happen largely (though not exclusively) outside of conscious awareness. This is an area for further research.

How might performance benefits impact the potential uptake of EVs?

How drivers construe performance

Modern electric powertrains have the potential to provide benefits over conventional ICE vehicles in both the dimensions of performance identified in this research, dynamic and cruising performance. An electric drive is clearly better than an ICE engine in terms of cruising performance, being both much quieter and much smoother (indeed, it offers these benefits at all speeds, not just when cruising). However if sufficiently powerful it can also offer benefits in terms of dynamic performance, given its torque characteristics that yield particularly high responsiveness and fast acceleration from low speeds. Such benefits are now being realized in practice. In the field study, in which around two hundred mass-market consumer drivers were given direct experience of using a modern BEV (Nissan Leaf), drivers rated both the cruising and dynamic performance of the car significantly more highly than drivers in a control group rated the performance of an equivalent ICE car (Ford Focus diesel).

Both BEVs and E-REVs should be able to offer both dynamic and cruising performance benefits over ICE vehicles, because in each of these types the vehicle is under electric drive at all times (although in an E-REV when the series range extender ICE is operating, quietness when cruising may be somewhat reduced). A parallel powertrain PHEV, however, will offer no particular cruising performance benefit (since, at cruising speeds, PHEVs typically operate under ICE power), and its dynamic performance benefits may be more limited than those of a BEV or E-REV. However, since the ICE in a PHEV has a more restricted range of operating conditions than in a conventional ICE powered car, it may be possible to reformulate fuels for PHEVs so as to yield lower noise and higher smoothness when cruising than a conventional ICE car.

Perception of performance

Although electric drive can offer both cruising and dynamic performance benefits compared with conventional ICE drive, it may be that the dynamic performance benefits in modern electric vehicles are not yet optimal. Modern BEVs are very constrained in terms of electric range, and this is such a major disadvantage to mass-market consumer drivers that it greatly outweighs the benefits of better performance for a large majority. Some of the dynamic performance benefits might therefore fruitfully be traded off to give vehicles some additional range: perhaps it would be disadvantageous to provide acceleration benefits that are much greater than the perceptual difference thresholds measured here. Even if the dynamic performance benefits were made smaller than the perceptual difference threshold, the EV might still feel more “fun to drive” to a driver able to experience driving it for long enough to have implicitly learnt its performance, and used that learning in driving it. We have seen that this might happen after only around 30 minutes of driving time in a road and traffic situation that elicits multiple accelerations.

For drivers of PHEVs, electric range is a much less critical issue. However PHEV drivers will not experience the cruising performance benefits of an electric drive, since PHEVs use their internal combustion engines at cruising speeds. Nor will they experience the full set of dynamic performance benefits, because accelerations will tend to be made in blended mode, with both electric drive and ICE contributing in parallel. They could, however, potentially still experience some dynamic performance benefits, such as responsiveness and acceleration from standing start, when the electric drive operates alone.

Electric range is also a much less critical issue for E-REVs, but since the final drive is always electric, they can in principle offer the same dynamic and cruising performance benefits as a BEV. It may be that substantial dynamic and performance benefits could help to offset their main disadvantage, high purchase cost; there are many instances of higher-performing cars being able to command a price premium in the market. Pending any major breakthrough in battery technology that might extend the electric range of BEVs (and/or reduce their recharging times), E-REVs will perhaps offer the most compelling set of benefits to mass-market consumer drivers in the medium term.

Symbolic meaning

Electric vehicles have a distinct symbolic meaning. Using a BEV signals that the user is significantly higher than average in openness, conscientiousness and agreeableness, and no different than average in extraversion and neuroticism. It also signals that he/she is of higher than average status, more likely than average to have high relationship investment, and more likely to be older than 35.

Self-congruity theory predicts that people will buy products whose meanings are consistent with their self-concepts. My research confirmed this in the case of BEVs, finding that willingness to consider having a BEV with a short electric range (comparable to the present generation of BEVs) was associated with high self-congruity (i.e. a degree of matching between the five-factor personality traits of the user, and those signalled by the BEV).

Although the symbolic meaning of good cruising performance is consistent with the symbolic meaning of EVs, that of good dynamic performance is not. This discongruity may mean that the symbolic value of the improved dynamic performance of EVs is limited, because it is inconsistent with the self-concepts of potential early adopters of EVs. Again this suggests that large dynamic performance benefits should not be provided in BEVs at the expense of electric range.

I was not able to measure the symbolic meaning of PHEVs or E-REVs. A starting point might be to assume it is reasonably similar to that of BEVs, but the unrestricted range, and higher CO₂ emissions might both contribute to different symbolic meanings, with a less pro-environmental flavour. Thus the issue of the discongruity between the symbolic meaning of dynamic performance benefits and the symbolic meanings of the vehicles may affect PHEVs and E-REVs to a lesser extent, or not at all. This is clearly an area for further study.

Conclusion

This research has examined how drivers construe, perceive and value vehicle performance, with the aim of informing the future design of EVs and fuels for PHEVs and E-REVs. The overall conclusion is that electric drivetrains can offer substantial performance benefits, which might help

to offset some of the disadvantages of the various EV types. However for BEVs, the disadvantages of short electric range outweigh these benefits for a large majority of mass-market consumer drivers, and in any case dynamic performance is discongruent with the personal identities of people likely to be early adopters (for whom pro-environmental motivations are often paramount). E-REVs, on the other hand, can deliver both the same range as a conventional car, and the performance benefits of an electric powertrain. If technical development leads to reduction in the high purchase costs, these may therefore have widespread appeal.

Appendix 1. A supplement to Experiment 6: Individual differences in overall frequency of decisions to overtake

Study 6 investigated the role of one influence on drivers' decisions to overtake, that of implicit learning of the performance of the vehicle. This Appendix considers another influence, that of individual dispositional differences, that was studied in a supplement to Experiment 6.

In the IGD model of driving (Chapter Four), driving behaviour is influenced by personality traits, reflected in chronically active higher level goals that send excitatory and inhibitory output to the Activity goals that determine behaviour. Thus the IGD model predicts that to some extent decisions to overtake will be influenced by personality traits. In Experiment 2 there were substantial individual differences in driving behaviour, and evidence that these could be predicted to some extent by FFM personality traits. In particular, dynamic driving styles were associated with low conscientiousness, low agreeableness and high neuroticism. It seems likely that motivation to overtake is likely to be associated with dynamic driving styles, so I hypothesise that drivers with these traits are likely to make more frequent positive decisions to overtake than other drivers.

The Theory of Planned Behaviour (Ajzen, 1985, 1991, 2005) predicts that a specific behaviour is more likely if a person perceives they have a high degree of control over its successful outcome (Perceived Behavioural Control, PBC). In Bandura's socio-cognitive theory (1977, 1995, 1997) the related notion of *self-efficacy*, peoples' beliefs in their capabilities to produce desired effects by their actions, plays a key role. Self-efficacy is seen as a general personality disposition, in which people exhibit individual differences. People with high self-efficacy choose to perform more challenging tasks (Bandura, 1995; Schwarzer & Born, 1997). Therefore it seems reasonable that frequency of decisions to overtake, particularly when opportunities are more difficult, will also be predicted by peoples' perceived self-efficacy.

Ajzen (2005) has argued that broad response predictors (such as personality traits) are often poor predictors of specific actions, but that greater predictive power can be achieved if dispositions are characterised at a level of specificity consistent with the actions themselves. This suggests that

dispositional measures of driving style might be better predictors of individual differences in frequency of decisions to overtake than general personality traits. The Multi-Dimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004) characterises driving style in terms of eight dimensions: Dissociative, Anxious, Risky, Angry, High Velocity, Distress Reduction, Patient and Cautious, based on self-report. Several of these dimensions (e.g. "Risky") might be predictors of individual differences in frequency of decisions to overtake. It also suggests that a driving-specific measure of self-efficacy such as Adelaide Driving Self-Efficacy Scale (ADSES) (George, Clark, & Crotty, 2007) might be a better predictor than a general self-efficacy measure such as the General Self-Efficacy scale (GSE) (Schwarzer & Born, 1997).

Experiment 6 therefore included a supplementary study of FFM personality traits, self-efficacy and self-reported driving style, as predictors of individual differences in frequency of decisions to overtake.

Method

Participants in Experiment 6 completed a battery of self-report questionnaires after their experimental drives:

1. IPIP-NEO personality inventory (120 items; Goldberg et al., 2006)
2. General Self-Efficacy questionnaire (GSE: 10 items)
3. Adelaide Driving Self-Efficacy Scale (ADSES: 12 items).
4. Multi-Dimensional Driving Style Inventory (MDSI; 44 items).

In addition to the MDSI self-report measure of driving style, a behavioural measure was also included based on driving behaviour in Zones 2, 4 and 6. Each of these zones included a road narrowing feature (a narrow bridge with stone walls to either side). Narrowing features can be used for psychological traffic calming (Kennedy et al, 2005), since they typically induce drivers to slow down. High entry speed to the bridge feature was assumed to be indicative of risk-taking propensity, and therefore hypothesized to be predictive of higher frequency of positive overtaking

decisions. Mean entry speed was calculated for each participant from the total of twelve bridge entries (four drives × three bridges per drive).

Participants’ overall frequency of positive overtaking decisions was calculated as a fraction of the total of twenty opportunities presented (four drives × five opportunities per drive).

Results

Pearson’s r correlation coefficients were calculated for overtaking frequency versus each of the potential predictor variables. Table A1-1 shows the statistically significant associations.

Predictor	Correlation Coefficient (Pearson’s r)	p
IPIP-NEO: Agreeableness	-0.436	0.003
<i>General Self-Efficacy (GSE)</i>	<i>0.275</i>	<i>0.065</i>
Adelaide Driving Self-Efficacy Scale (ADSES)	0.336	0.022
MDSI: Risky scale	0.393	0.007
MDSI: Anxious scale	-0.351	0.017
Mean entry speed to road narrowing feature	0.610	< 0.001

Table A1-1. Significant associations between frequency of positive decisions to overtake and predictor variables

The correlation with the GSE is included for comparison with that for the ADSES as it was close to statistical significance

Discussion

The personality trait of low agreeableness was associated with higher frequency of positive overtaking decisions. That is consistent with the finding in Experiment 2 that low agreeableness is

associated with dynamic driving styles involving greater use of acceleration and subsequent braking. In Experiment 2, dynamic driving was also associated with low conscientiousness and high neuroticism, but only weak, non-significant correlations with these were found in the supplementary study.

A sense of self-efficacy appears to be associated with higher frequency of positive overtaking decisions, particularly when measured in relation to the specific activity of driving, using the ADSES, rather than the more globally applicable GSE. This is consistent with both TPB and Bandura's self-efficacy theory.

Two aspects of self-reported driving style were also associated higher frequency of positive overtaking decisions: Risky driving (associated positively) and Anxious driving (associated negatively). Given the inherent risks involved in overtaking, particularly when the difficulty level is high, this finding provides support for the validity of both the Risky and Anxious scales of the MDSI. A Risky driving style was shown in Chapter Nine to be symbolic of low agreeableness, so the findings here are consistent.

The findings also provide some support for Ajzen's (2005) argument that greater predictive power can be achieved if dispositions are characterised at a level of specificity consistent with the actions themselves. In the supplementary study, driving-specific self-efficacy was more closely correlated with frequency of positive overtaking decisions than general self-efficacy; and the behavioural measure of driving style (mean entry speed to the road narrowing feature) was the most closely correlated of all the measures to higher frequency of positive overtaking decisions. Self-reported driving style was also more closely associated with frequency of positive overtaking decisions than the general personality traits of conscientiousness and neuroticism, though this was not the case for agreeableness, which appears in this thesis to be a rather useful predictor of driving behaviour.

Appendix 2. NRS classification system for socio-economic group

The NRS system of socio-economic groups (SEGs) is a demographic classification used in the United Kingdom. It was originally developed by the National Readership Survey (<http://www.nrs.co.uk/lifestyle.html>) to classify readers, but is now widely used. Group definitions are now maintained by the UK Market Research Society. The distinguishing feature of the SEG classification is that it is based on the occupations of heads of households. It is summarised in Table A2-1.

SEG	% in UK population (in 2008)	Description	Occupation of main income earner in household
A	4	<u>upper middle class</u>	Higher managerial, administrative or professional
B	23	<u>middle class</u>	Intermediate managerial, administrative or professional
C1	29	<u>lower middle class</u>	Supervisory or clerical and junior managerial, administrative or professional
C2	21	<u>skilled working class</u>	Skilled manual workers
D	15	<u>working class</u>	Semi and unskilled manual workers
E	8	those at the lowest levels of subsistence	Casual or lowest grade workers, pensioners, and others who depend on the welfare state for their income

Table A2-1. NRS classification system for socio-economic group

The NRS system remains in widespread use in market research because it is familiar, has discriminatory power and is simple to use: gathering data on occupation is usually straightforward. For these reasons it was used in the studies reported here. However it is now a dated system that in some respects fails to reflect current social reality in the UK. For instance, there are now many more households in the UK where two partners both work, so attributing SEG to the lower earner

of the two of the basis of the occupation of the higher earner has questionable validity. The UK government Office of National Statistics now uses an alternative system, the National-Statistics Socio-Economic Classification (NS-SEC), in government social research.

References

- Aarts, H., & Dijksterhuis, A. (2003). The Silence of the Library: Environment, Situational Norm, and Social Behavior. *Journal of Personality and Social Psychology*, 84, 18-28.
- Aarts, H., & Elliot, A. J. (Eds.) (2012). *Goal-Directed Behavior*. Hove, England: Psychology Press.
- Adler, T., Wargelin, L., Kostyniuk, L., Kavalec, C., & Occhuizzo, G. (2003). Incentives for Alternate Fuel Vehicles: A Large-Scale Stated Preference Experiment. *Tenth International Conference on Travel Behaviour Research*, Lucerne.
- Af Wahlberg, A. (2009). *Driver Behaviour and Accident Research Methodology*. Farnham, England: Ashgate.
- af Wahlberg, A., Dorn, L., de Winter, J. C.F., Dodou, D., & Freeman, J. E. (2012). Commentaries and responses to "The Driver Behaviour Questionnaire as a Predictor of Accidents : A Meta-analysis". *Journal of Safety Research*, 43(1), 83-99.
- Ajvalasit, M., & Giacomini, J. (2007). Effect of automobile operating condition on the subjective equivalence of steering wheel vibration and sound. *International Journal of Vehicle Noise and Vibration*, 3(2), 197-215.
- Ajvalasit, M., & Giacomini, J. (2009). A Survey Study of Steering Wheel Vibration and Sound in Automobiles at Idle. *Journal of the Engineering Integrity Society*, 26, 6-14.
- Ajzen, I. (1985). From intentions to actions: A theory of planned behaviour. In J. Kuhl & J. Beckman (Eds.), *Action-Control: From Cognition to Behavior* (pp.11-39). Heidelberg, Germany: Springer.
- Ajzen, I. (1991). A theory of planned behaviour. *Organizational Behaviour and Human Decision Processes*, 50, 179-211.
- Ajzen, I. (2005). *Attitudes, Personality and Behaviour*. Maidenhead, England: Open University Press.

Allen, M. R., Frame, D. J., Huntingford, C., Jones, C. D., Lowe, J. A., Meinshausen, M., & Meinshausen, N. (2009). Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature*, 458, 1163-1166.

Alm, H. (1995). *Driving Simulators as Research Tools—A Validation Study Based on the VTI Driving Simulator*. In: DRIVE II V2065: GEM Validation Studies - Appendix, Reference. GEM/TR/TRC/MK950327, Work package 500, Deliverable No. 10, Rover, British Aerospace, Philips Research Laboratories, TNO Institute for Perception, Kara (COSILY), ACit GmbH, TRC University of Groningen, University of Leeds, VTI.

Alvarez-Daziano, R., & Bolduc, D. (2009). Canadian consumers' perceptual and attitudinal responses toward green automobile technologies: an application of Hybrid Choice Models. 2009 *EAERE-FEEM-VIU European Summer School in Resources and Environmental Economics: Economics, Transport and Environment*, Venice.

Anderson, J. R. (1976). *Language, memory, and thought*. Cambridge, MA: Harvard University Press.

Anderson, J. R. (1983a). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Anderson, J. R. (1983b). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior*, 22, 261-295.

Anderson, J. R. (1993). *Rules of the mind*. Hillsdale, NJ: Erlbaum.

Arthur, W., & Graziano, W. G. (1996). The Five-Factor Model, Conscientiousness, and Driving Accident Involvement. *Journal of Personality*, 64, 3, 593-618.

Aschenbrenner, K. M., Biehl, B., & Wurm, G. W. (1987). Einfluß Der Risikokompensation auf die Wirkung von Verkehrssicherheitsmassnahmenam Beispiel ABS. *Schriftenreihe Unfall- und Sicherheitforschung Straßenverkehr*, Heft 63 Bergisch Gladbach, Bundesanstalt für Strassenwesen (BASt), 65-70.

Ascher, D., & Grzywacz, N. M. (2000). A Bayesian model for the measurement of visual velocity. *Vision Research*, 40, 3427-3434.

Augustine, St. (397). *On Christian Teaching*. R.P.H. Green (Ed.) (2008), Oxford, England: Oxford Paperbacks.

Austen, J. (1813). *Pride and Prejudice*. Penguin Classics 2nd Edition (2005). London, England: Penguin.

Axsen, J., & Kurani, K. S. (2012). Interpersonal influence within car buyers' social networks: applying five perspectives to plug-in hybrid vehicle drivers. *Environmental Planning Part A*, 44, 1057–1065.

Axsen, J., & Kurani, K. (2013). Hybrid, plug-in hybrid, or electric – What do car buyers want? *Energy Policy*, 61, 532-543.

Axsen, J., Orlebar, C., & Skippon, S. (2013). Social influence and consumer preference formation for pro-environmental technology: The case of a UK workplace electric-vehicle study. *Ecological Economics*, 95, 96-107.

Ayama, M., Hasegawa, H., Kawaguchi, M., Ihata, N., Ikegami, M., & Kasuga, M. (2002). A study to measure spare capacity of driver's attention payable to cognitive subtask. *IEEE 5th International Conference on Intelligent Transportation Systems, Singapore*.

Baber, C. (2004). Repertory Grid for Product Evaluation. In N. Stanton, A. Hedge, K. Brookhuis, E. Salas, & H. Hendrick (Eds.), *Handbook of Human Factors and Ergonomics Methods*. Boca Raton, FL.: CRC Press.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioural change. *Psychological Review*, 84, 191-215.

Bandura, A. (Ed.) (1995). *Self-efficacy in changing societies*. Cambridge, England: Cambridge University Press.

- Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York, NY: Freeman.
- Banase, R. (2003). Beyond Verbal Self-Report: Priming Methods in Relationship Research. In J. Musch & K. C. Klauer (Eds.) *The Psychology of Evaluation*. Mahwah, NJ: Lawrence Erlbaum.
- Bargh, J. A. (1997). The Automaticity of Everyday Life. In R. S. Wyer (Ed.), *Advances in Social Cognition, Volume X*. Urbana-Champaign, IL: University of Illinois.
- Bargh, J. A. (2007). *Social Psychology and the Unconscious: The Automaticity of Higher Mental Processes*. Hove, England: Psychology Press.
- Bargh, J.A., & Chartrand, T.L. (2000). The mind in the middle: A practical guide to priming and automaticity research. In H.T. Reis & C.M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp.253-285). Cambridge, England: Cambridge University Press.
- Bargh, J.A., Gollwitzer, P.M., Lee-Chai, A., Barndollar, K., & Trötschel, R. (2001). The automated will: nonconscious activation and pursuit of behavioral goals. *Journal of Personality & Social Psychology*, 81, 1014–1027.
- Baumeister, R. F., & Vohs, K.D. (2004). Understanding self-regulation: An introduction. In R. Baumeister & K. Vohs (Eds.), *Handbook of self-regulation: Research theory and applications*. New York, NY: Guilford Press.
- Bechtold, R. L. (1997). *Alternative Fuels Guidebook: Properties, Storage, Dispensing and Vehicle Facility Modifications*. Warrendale, PA: Society of Automotive Engineers.
- Belk, R. W. (1985). Materialism: Trait Aspects of Living in the Material World. *Journal of Consumer Research*, 12, 265-280.
- Benet-Martinez, V., & John, O. P. (1998). Los Cinco Grandes across cultures and ethnic groups: multitrait – multimethod analyses of the Big Five in Spanish and English. *Journal of Personality and Social Psychology*, 75, 729-750.

Benfield, J. A., Szlemko, W. J., & Bell, P. A. (2007). Driver Personality and anthropomorphic attributions of vehicle personality relate to reported aggressive driving tendencies. *Personality and Individual Differences*, 42, 247-258.

Bennett, B. M., Hoffman, D. D., & Prakash, C. (1989). *Observer Mechanics*. London, England: Academic Press.

Bennett, B. M., Hoffman, D. D., Prakash, C., & Richman, S. N. (1996). Observer theory, Bayes theory and psychophysics. In D. C. Knill & W. Richards (Eds.), *Perception as Bayesian Inference*. Cambridge, England: Cambridge University Press.

Berger, A. A. (2010). *The Objects of Affection: Semiotics and Consumer Culture*. New York, NY: Palgrave McMillan.

Berry, D. C. (Ed.) (1997). *How Implicit is Implicit Learning?* Oxford, England: Oxford University Press.

Berry, D. C., & Broadbent, D. E. (1984). On the relationship between task performance and verbal knowledge. *Quarterly Journal of Experimental Psychology*, 36A, 209-321.

Berry, D. C., & Broadbent, D. E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology*, 79, 251-272.

Bex, P. J., Bedingham, S., & Hammett, S. T. (1999). Apparent speed and speed sensitivity during adaptation to motion. *Journal of the Optical Society of America A*, 16, 2817-2824.

Birn, R. J. (2002). *The International Handbook of Market Research Techniques*. London, England: Kogan Page.

Blaauw, G. J. (1982). Driving experience and task demands in simulator and instrumented car: a validation study. *Human Factors*, 24, 473-486.

Blaauw, G. J. (1984). *Car Driving as a Supervisory Control Task*. PhD Thesis. TNO Institute for Perception, Soesterberg, the Netherlands.

- Blakemore, C., & Cooper, G. F. (1970). Development of the brain depends on the visual environment. *Nature*, 228, 477-478.
- Blumer, H. (1937). Social Psychology. In E. Schmidt (Ed.), *Man and Society*. New York, NY: Prentice Hall.
- Boff, K. R., & Lincoln, J. E. (1988) *Engineering Data Compendium: Human Perception and Performance*. Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, OH: United States Air Force.
- Borg, G. (1961). *On the perception of speed when car-driving*. Umea, Sweden: University of Umea Medical School, Department of Psychiatry.
- Borg, G. (1998). *Borg's Perceived Exertion and Pain Scales*, Champaign, IL: Human Kinetics.
- Born, R. T., & Bradley, D. C. (2005). Structure and function of visual area MT. *Annual Review of Neuroscience*, 28, 157-189.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3, 77-101.
- Brandt, T., Dichgans, J., & Koenig, E. (1973). Differential Effects of Central versus Peripheral Vision on Egocentric and Exocentric Motion Perception. *Experimental Brain Research*, 16, 476-491.
- Bregman, A. S. (1999). *Auditory Scene Analysis: The Perceptual Organization of Sound*. Cambridge, MA.: MIT Press.
- Breitmeyer, B. G. (2007). *Visual masking: past accomplishments, present status, future developments*. *Advances in Cognitive Psychology* 3(1-2), 9-20.
- Breitmeyer, B. G., & Ögmen, H. (2006). *Visual Masking: Time Slices Through Conscious and Unconscious Vision*. Oxford, England: Oxford University Press.

Bridgeman, B. (1992). Conscious vs. unconscious processing: the case of vision. *Theory & Psychology*, 2, 73-88.

Broadbent, D. E. (1977). Levels, hierarchies, and the locus of control. *Quarterly Journal of Experimental Psychology*, 29, 181-201.

Broadbent, D. E. & Aston, B. (1978). Human control of a simulated economic system. *Ergonomics*, 21, 1035-1043.

Broadbent, D. E., FitzGerald, P., & Broadbent, M. H. P. (1986). Implicit and explicit knowledge in the control of complex systems. *British Journal of Psychology*, 77, 33-50.

Brownstone, D., Brunch, D., & Train, K. (2000). Joint Mixed Logit Models of Stated and Revealed Preferences for Alternative-Fuelled Vehicles. *Transportation Research Part B: Methodological*, 34, 315-338.

Bruno, N., & Cutting, J.E. (1988). Multimodularity and the perception of layout. *Journal of Experimental Psychology: General*, 117, 161-170.

Buczynsky, A. (1993). Effects of Driveability Index and MTBE on Driver Satisfaction at Intermediate Ambient Temperatures. *SAE Technical Papers Series*, 932671. Warrendale, PA., Society of Automotive Engineers.

Bullier, J. (2001). Integrated model of visual processing. *Brain Research Reviews*, 36, 96-107.

Bunch, D. S., Bradley, M., Golob, T. F., Kitamura, R. & Occhiuzzo, G. P. (1993). Demand for clean-fuel vehicles in California: A discrete-choice stated preference pilot project. *Transportation Research Part A: Policy & Practice*, 27, 237-253.

Burgess, M., King, N., Harris, M., & Lewis, E. (2013). Electric vehicle drivers' reported interactions with the public: driving stereotype change? *Transportation Research Part F: Traffic Psychology and Behaviour*, 17, 33-44.

- Buss, D. M. (1989). Sex differences in human mate preferences: Evolutionary hypotheses testing in 37 cultures. *Behavioural and Brain Sciences*, 12, 1-49.
- Campbell, D. T., & Stanley, J. C. (1963). Experimental and quasi-experimental designs for research on teaching. In N.L. Gage (Ed.), *Handbook of Research on Teaching*, Chicago: Rand McNally.
- Caperello, N., Kurani, K., & TyreeHageman, J. (2013). Do You Mind if I Plug-in My Car? How etiquette shapes PEV drivers' vehicle charging behavior. *Transportation Research Part A: Policy and Practice*, 54, 155-163.
- Carley, S., Krause, R. M., Lane, B. W., & Graham, J. D. (2013). Intent to purchase a plug-in electric vehicle: A survey of early impressions in large U.S. cities. *Transportation Research Part D: Transport and Environment*, 18, 39-45.
- Carsten, O. M. J., Groeger, J. A., Blana, E., & Jamson, A. H. (1997). *Driver Performance in the EPSRC Driving Simulator [LADS]: A Validation Study*. Final report for EPSRC project GR/K56162. Retrieved from: <http://mistrall.leeds.ac.uk/validation.html>.
- Carver, C. S., & Scheier, M. F. (1998). *On the Self-Regulation of Behavior*. Cambridge, England: Cambridge University Press.
- Cavallo, J. V. & Fitzsimmons, G. M. (2012). Goal Competition, Conflict, Coordination, and Completion: How Intergoal Dynamics Affect Self-Regulation. In H. Aarts & A. J. Elliot (Eds.), *Goal-Directed Behavior*. Hove, England: Psychology Press.
- Cavallo, V.E. & Cohen, A.S. (2001). Perception. in P-E Barjonet (Ed.), *Traffic Psychology Today*. Dordrecht, Netherlands: Kluwer Academic Publishers.
- Cellar, D. F., Nelson, Z. C. & Yorke, C. M. (2000). The Five-Factor Model and Driving Behaviour: Personality and Involvement in Vehicular Accidents. *Psychological Reports*, 86, 454-456.
- Chandler, D. (2007). *Semiotics: The Basics, 2nd Edition*. London, England: Routledge.

- Chaplin, L. N. & John, D. R. (2007). Growing up in a Material World: Age Differences in Materialism in Children and Adolescents. *Journal of Consumer Research*, 34, 480-493.
- Chapman, S. (1968). Catching a baseball. *American Journal of Physics*, 36, 868-870.
- Cheetham, C. (2003). *Sports Cars, High-Performance Machines*. Rochester, England: Grange Books.
- Cheetham, C. (2005). *Ultimate Performance Cars*. Minneapolis, MN: Motorbooks.
- Cheron, E., & Zins, M. (1997). Electric Vehicle Purchasing Intentions: The Concern over Battery Charge Duration. *Transportation Research Part A: Policy and Practice*, 31(3), 235-243.
- Chio, Y.-C., Song, H.-B., Lee, J.-H., & Cho, H.-S. (2003). An experimental study for driveability improvements in vehicle acceleration mode. *Proceedings of the Institution of Mechanical Engineers Part D, Journal of Automobile Engineering*, 217, 623-631.
- Chodosh, L., Lifson, L., & Tabin, C. (1995). On catching fly balls (skilfully). *Science*, 268, 1681.
- Choi, Y. S., Gray, H. M. & Ambady, N. (2005). The Glimpsed World: Unintended Communication and Unintended Perception. In R. R. Hassin, J. S. Uleman & J. A. Bargh (Eds.), *The New Unconscious*. New York: Oxford University Press USA.
- Choo, S., & Moktarian, P. (2002). *The Relationship of Vehicle Type Choice to Personality, Lifestyle, Attitudinal and Demographic Variables*, Report number UCD-ITS-RR-02-06, Davis, CA., University of California, Davis.
- Clifford, C. W., & Ibbotson, M. R. (2002). Fundamental mechanisms of visual motion detection: Models, cells and functions. *Progress in Neurobiology*, 68, 409-437.
- Clifford, C. W., & Langley, K. (1996). Psychophysics of motion adaptation parallels insect electrophysiology. *Current Biology*, 6, 1340-1342.
- Clifford, C. W., & Wenderoth, P. (1999). Adaptation to temporal modulation can enhance differential speed sensitivity. *Vision Research*, 39, 4324-4332.

- Cockerham, P. W. (1997). *BMW, Precision and Performance*. New York, NY: Todtri Productions.
- Cocron, P., Buhler, F., Neumann, I., Franke, T., Krems, J. F., Schwalm, M., & Keinath, A. (2011). Methods of evaluating electric vehicles from a user's perspective – the Mini E field trial in Berlin. *IET Intelligent Transport Systems*, 5(2), 127-133.
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences, Second Edition*. Mahwah, NJ: Lawrence Erlbaum.
- Cook, T. D. & Campbell, D. T. (1979). *Quasi-Experimentation: Design and Analysis Issues for Field Settings*. Chicago: Rand McNally.
- Cooley, C. H. (1902). *Human Nature and the Social Order*. New York, NY: Charles Scribner.
- Costa, P. T., & McCrae, R. R. (1992). *Revised NEO Personality Inventory (NEO PI-R) and NEO Five-Factor Inventory (NEO-FFI) professional manual*. Odessa, FL: Psychological Assessment Resources.
- Costa, P. T. & McCrae, R. R. (1995). Domains and Facets: Hierarchical Personality Assessment Using the Revised NEO Personality Inventory. *Journal of Personality Assessment*, 64, 1, 21-50.
- Csikszentmihalyi, M., & Rochberg-Halton, E. (1981). *The Meaning of Things: Domestic Symbols and the Self*. Cambridge, England: Cambridge University Press.
- Custers, R., Eitam, B., & Bargh, J.A. (2012). Conscious and Unconscious Processes in Goal Pursuit. In H. Aarts & A.J. Elliot (Eds.), *Goal-Directed Behavior*. Hove, England: Psychology Press.
- Dagdalen, M., Reymond, G., Kemeny, A., Bordier, M., & Maizi, N. (2009). Model-based predictive motion cueing strategy for vehicle driving simulators. *Control Engineering Practice*, 17(9), 995-1003.

- Dagsvik, J. K., Wennemo, T., Wetterwald, D. G., & Aaberge, R. (2002). Potential demand for alternative fuel vehicles. *Transportation Research Part B: Methodological*, 36, 361-384.
- Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York, NY: Putnam.
- Darwin, C. (1871). *The descent of man, and selection in relation to sex*. London, England: Murray.
- David, H. A. (1963). *The Method of Paired Comparisons*. London, England: Charles Griffin & Company.
- Davis, C. J. (2003). Factors Underlying Masked Priming Effects in Competitive Network Models of Visual Word Recognition. In S. Kinoshita & S. J. Lupker (Eds.), *Masked Priming: The State of the Art*. Hove, England: Psychology Press.
- De Houwer, J. (2003). A Structural Analysis of Indirect Measures of Attitudes. In J. Musch & K. C. Klauer (Eds.), *The Psychology of Evaluation*. Mahwah, NJ: Lawrence Erlbaum.
- De Houwer, J., & Moors, A. (2003). How to Define and Examine the Implicitness of Implicit Measures. In B. Wittenbrink & N. Schwarz (Eds.), *Implicit Measures of Attitudes*. New York, NY: Guilford Press.
- De Winter, J.C.F., & Dodou, D. (2010). The Driver Behaviour Questionnaire as a predictor of accidents: A meta-analysis. *Journal of Safety Research*, 41, 463-470.
- Deci, E. L., & Ryan, R. M. (2000). The “what” and “why” of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, 11, 227-268.
- Delang, C. O., & Cheng, W.-T. (2012). Consumers' attitudes towards electric cars: A case study of Hong Kong. *Transportation Research Part D: Transport and Environment*, 17, 492-494.
- Denton, G. G. (1980). The Influence of Visual Pattern on Perceived Speed. *Perception*, 9, 393-402.
- Dhar, R., & Wertenbroch, K. (2012). Self-Signaling and the Costs and Benefits of Temptation in Consumer Choice. *Journal of Marketing Research*, XLIX, 15-25.

- Dienes, Z., Broadbent, D. E., & Berry, D.C. (1991). Implicit and explicit knowledge bases in artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 17, 875-887.
- Dienes, Z., & Fahey, R. (1995). The role of specific instances in controlling a dynamic system. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 21, 848-862.
- Dienes, Z., & Fahey, R. (1998). The Role of Implicit Memory in Controlling a Dynamic System. *Quarterly Journal of Experimental Psychology, Section A: Human Experimental Psychology*, 51 (3), 593-614.
- Dienes, Z., & McLeod, P. (1993). How to catch a cricket ball. *Perception*, 22, 1427-1439.
- Dienes, Z., & Scott, R. B. (2005). Measuring unconscious knowledge: distinguishing structural knowledge and judgment knowledge. *Psychological Research*, 69, 338-351.
- Dienes, Z., Scott, R. B., & Seth, A. K. (2010). Subjective measures of implicit knowledge that go beyond confidence: Reply to Overgaard et al. *Consciousness and Cognition*, 19, 685-686.
- Dienes, Z., & Seth, A. (2010). Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition*, 19, 674-681.
- Dijksterhuis, A., Bos, M. W., Nordgren, L. F., & van Baaren, R. B. (2006). Complex choices better made unconsciously? *Science*, 313, 760-761.
- Dijksterhuis, A. & Nordgren, L. F. (2006). A theory of unconscious thought. *Perspectives on Psychological Science*, 1, 95-109.
- Dimitropoulos, A., Rietveld, P., & van Ommeren, J. N. (2013). Consumer valuation of changes in driving range: A meta-analysis. *Transportation Research Part A: Policy and Practice*, 55, 27-45.
- Dittmar, H. (1992). *The social psychology of material possessions: To have is to be*. Hemel Hempstead, England: Harvester Wheatsheaf.

Dittmar, H., & Brown, R. (2008). *Consumer Culture, Identity and Well-Being: The Search for the 'Good Life' and the 'Body Perfect'*. Hove, England: Psychology Press.

Dolfsma, W. (2008). *Consuming symbolic goods: Identity and Commitment, Values and Economics*. Abingdon, England: Routledge.

Dorey, R. E., & Holmes, C. B. (1999). Vehicle Driveability – Its Characterisation and Measurement. *SAE Technical Papers Series, 1999-01-0949*. Warrendale, PA.: Society of Automotive Engineers.

Dorey, R. E. & Martin, E. J. (2000). Vehicle Driveability – The Development of an Objective Methodology. *SAE Technical Papers Series, 2000-01-1326*. Warrendale, PA.: Society of Automotive Engineers.

Dosher, B. A., Sperling, G. & Wurst, S. (1986). Tradeoffs between stereopsis and proximity luminance covariance as determinants of perceived 3D structure. *Vision Research*, 26, 973-990.

Dudleston, A., Hewitt, E., Stradling, S., & Anable, J. (2005). *Public Perceptions of Travel Awareness – Phase 3*. Edinburgh, Scotland: Scottish Executive Social Research.

Dunn, M. J., & Searle, R. (2010). Effect of manipulated prestige-car ownership on both sex attractiveness ratings. *British Journal of Psychology*, 101, 69-80.

Eastman, J., Goldsmith, R., & Flynn, L. (1999). Status Consumption in Consumer Behaviour: Scale Development and Validation. *Journal of Marketing Theory and Practice*, 7(3), 41-51.

Ehsani, M., Gao, Y., & Emadi, A. (2009). *Modern Electric, Hybrid Electric and Fuel Cell Vehicles. 2nd Edition*. New York, NY: CRC Press.

Einstein, A. (1907). Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen. *Jahrbuch der Radio-aktivitat und Elektronik*, 4, 411-462.

- Ellaway, A., Macintyre, S., Hiscock, R., & Kearns, A. (2003). In the driving seat: psychosocial benefits from private motor vehicle transport compared with public transport. *Transportation Research Part F: Traffic Psychology & Behaviour*, 6, 217-231.
- Energy Technologies Institute (2013). *Transport: An affordable transition to sustainable and secure energy for light vehicles in the UK*. Loughborough, England: Energy Technologies Institute.
- England, M. H., Sen Gupta, A., & Pitman, A. J. (2009). Constraining future greenhouse gas emissions by a cumulative target. *Proceedings of the National Academy of Sciences*, 106, 16539-16540.
- Enns, J. T., & Di Lollo, V. (2000). What's new in visual masking? *Trends in Cognitive Sciences*, 4, 345-352.
- Eriksen, M. (1996). Using Self-Congruity and Ideal Congruity to Predict Purchase Intention: A European Perspective. *Journal of Euro-Marketing*, 6(1), 41-56.
- Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, 415, 429-433.
- Evans, L. (1970) Speed estimation from a moving automobile. *Ergonomics*, 13, 219-230.
- Everitt, B. (1974). *Cluster Analysis*, New York, NY: Heinmann.
- Eysenck, H. J., & Eysenck, S. B. G. (1975). *The Eysenck Personality Questionnaire*, London, England: Hodder & Stoughton.
- Fazio, R. H., Sambonmatsu, D. M., Powell, M. C., & Kardes, F. R. (1986). On the automatic activation of attitudes. *Journal of Personality and Social Psychology*, 50, 229-238.
- Försterling, F. (2001). *Attribution: An Introduction to Theories, Research and Applications*. Hove, England: Psychology Press.
- Fournier, S. (1991). A Meaning-Based Framework for the Study of Consumer-Object Relations. *Advances in Consumer Research*, 18, 736-742.

- Fraine, G., Smith, S. G., Zinkiewicz, L., Chapman, R., & Sheehan, M. (2007). At home on the road? Can drivers' relationships with their cars be associated with territoriality? *Journal of Environmental Psychology*, 27, 204-214.
- Franke, T., & Krems, J. F. (2013a). Interacting with limited mobility resources: Psychological range levels in electric vehicle use. *Transportation Research Part A: Policy and Practice*, 48, 109-122.
- Franke, T., & Krems, J. F. (2013b). Understanding charging behaviour of electric vehicle users. *Transportation Research Part F: Traffic Psychology and Behaviour*, 21, 75-89.
- Fransella, F., Bell, R., & Bannister, D. (2004). *A Manual for Repertory Grid Technique*, 2nd edition. Chichester, England: Wiley.
- French, R. M., & Cleeremans, A. (2002). *Implicit Learning and Consciousness: An empirical, philosophical and computational consensus in the making*. Hove, England: Psychology Press.
- Freud, S. (1915). Das Unbewußte. *Internationale Zeitschrift für ärztliche Psychanalyse*, 3 (3).
- Frost, A. (1981). Business applications of repertory grid. *Journal of the Market Research Society* 24, 81-83.
- Fukuhara, C., Kamura, T., And Suetomi, T. (2002). Subjective evaluation of engine acceleration sound with driving simulator. *JSAE Review* 23, 435-441.
- Fuller, R. (2000). The task-capability interface model of the driving process. *Recherche Transports Sécurité*, 66, 47-59.
- Fuller, R. (2011). Driver Control Theory. In B.E. Porter (Ed.), *Handbook of Traffic Psychology*. Amsterdam, Netherlands: Elsevier.
- Fuller, R., McHugh, C., & Pender, S. (2008). *Task difficulty and risk in the determination of driver behaviour*. *European Review of Applied Psychology*, 58, 13-21.

- Funk, K., & Rabl, A. (1999). Electric versus conventional vehicles: social costs and benefits in France. *Transportation Research Part D: Transport and Environment*, 4, 397-411.
- Furnham, A., & Saipe, J. (1993). Personality correlates of convicted drivers. *Personality and Individual Differences*, 14, 329-336.
- Gaertner, S. L., & McLaughlin, J. P. (1983). Racial stereotypes: Associations and ascriptions of positive and negative characteristics. *Social Psychology Quarterly*, 46, 23-30.
- Gangestad, S. W., & Simpson, J. A. (2000). The evolution of human mating: Trade-offs and strategic pluralism. *Behavioral and Brain Sciences*, 23, 573-644.
- Gardner, B., & Abraham, C. (2007). What drives car use? A grounded theory analysis of commuters' reasons for driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(3), 187-200.
- Geddes, B.W., & Stevenson, R.J. (1997). Explicit Learning of a Dynamic System with a Non-salient pattern. *Quarterly Journal of Experimental Psychology*, 50A (4), 742-765.
- Geisler, W.S., & Kersten, D. (2002). Illusions, perception and Bayes. *Nature Neuroscience*, 5(6), 508-510.
- George, S., Clark, M., & Crotty, M. (2007). Development of the Adelaide Driving Self-Efficacy Scale. *Clinical Rehabilitation*, 21, 56-61.
- Gescheider, G. A. (1997). *Psychophysics: The Fundamentals*, 3rd Edition. Mahwah, NJ: Lawrence Erlbaum.
- Ghahramani, Z., Wolpert, D. M., & Jordan, M. I. (1997). Computational models of sensorimotor integration. In P. G. Morasso & V. Sanguineti (Eds.), *Self-organization, computational maps, and motor control*. Amsterdam, Netherlands: Elsevier.
- Gibson, J. J. (1950). *The Perception of the Visual World*. Boston, MA.: Houghton Muffin.

- Gibson, J. J. (1966). *The Senses Considered as Perceptual Systems*. Boston, MA.: Houghton Muffin.
- Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Hillsdale, NJ.: Lawrence Erlbaum Associates.
- Gilovich, T., Griffin, D., & Kahneman, D. (2002). *Heuristics and Biases: The Psychology of Intuitive Judgment*. Cambridge, England: Cambridge University Press.
- Girden, E. R. (1992). *ANOVA: repeated measures*. Newbury Park, CA: Sage.
- Glaser, B. G., & Strauss, A. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Piscataway, NJ.: Aldine Transaction.
- Glover, A. R., Skippon, S. M., & Boyle, R. D. (1995). Interferometric laser imaging for droplet sizing: A method for droplet-size measurement in sparse sprays. *Applied Optics*, 34(36), 8409-8421.
- Godley, S. T., Triggs, T. J., & Fildes, B. N. (2004). Perceptual lane width, wide perceptual centre road markings and driving speeds. *Ergonomics*, 47(3), 237-256.
- Goldberg, L. R. (1981). Language and individual differences: The search for universals in personality lexicons in L. Wheeler (Ed.), *Review of Personality and Social Psychology Vol. 2*, 141-165, Beverley Hills, CA, Sage.
- Goldberg, L. R., Johnson, J. A., Eber, H. W., Hogan, R., Ashton, M. C., Cloninger, C. R., & Gough, H. G. (2006). The international personality item pool and the future of public-domain personality measures, *Journal of Research in Personality* 40, 84-96.
- Goldstein, A. G. (1957). Judgements of visual velocity as a function of length of observation time. *Journal of Experimental Psychology*, 54, 457-461.
- Goldstein, E. B. (Ed.) (2001). *Blackwell Handbook of Perception*. Oxford, England: Blackwell.

- Golias, I., & Karlaftis, M.G. (2002). An international comparative study of self-reported driver behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, 4, 243-256.
- Golob T. F., & Gould, J. (1998). Projecting use of electric vehicles from household vehicle trials. *Transportation Research Part B: Methodological*, 32, 441-454.
- Goodale, M. A., & Humphrey, G. K. (1998). The objects of action and perception. *Cognition*, 67, 181-207.
- Goodale, M. A., & Humphrey, G. K. (2001). Separate Visual Systems for Action and Perception. In E.B. Goldstein (Ed.) *Blackwell Handbook of Perception*. Oxford, England: Blackwell.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15(1), 20-25.
- Goodrich, R. A. (1999). Deconstructing Constructs: Pitfalls in Personal Construct Theory. *Educational Philosophy and Theory* 31, 71-82.
- Goodwin, P. B. (1997). Mobility and car dependence, in T. Rothengatter & E. Carbonell Vaya (Eds.), *Traffic and Transport Psychology: theory and application*. Oxford, England: Pergammon.
- Gordon, W., & Langmaid, R. (1988). *Qualitative Research: A practitioner's and buyer's guide*. Aldershot, England: Gower Publishing.
- Gosling, S. D., Rentfrow, P. J., & Swann, W. B. (2003). A very brief measure of the Big-Five personality domains. *Journal of Research in Personality*, 37(6), 504-528.
- Gould, J., & Golob, T. F. (1998). Clean Air Forever? A Longitudinal Analysis of Opinions About Air Pollution and Electric Vehicles. *Transportation Research Part D: Transport and Environment*, 3(3), 157-169.
- Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., et al. (2012). Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A

- qualitative analysis of responses and evaluations. *Transportation Research Part A: Policy and Practice*, 46, 140-153.
- Graham-Rowe, E., Skippon, S., Gardner, B., & Abraham, C. (2011). *Can we reduce car use and, if so, how? A review of available evidence*. *Transportation Research Part A: Policy and Practice*, 45, 401-418.
- Greenhouse, S. W. & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, 24, 95-112.
- Gregory, R. L. (1980). Perceptions as hypotheses. *Philosophical Transactions of the Royal Society of London, Series B*, 290, 181-197.
- Greenwald, A. G., Klinger, M. R., & Liu, T. J. (1989). Unconscious processing of dichoptically masked words. *Memory and Cognition*, 17(1), 35-47.
- Greenwald, A. G., McGhee, D. E., & Schwartz, J. L. K. (1998). Measuring individual differences in individual cognition: The Implicit Association Test. *Journal of Personality and Social Psychology*, 74, 1464-1480.
- Griskevicius, V., Tybur, J. M., Sundie, J. M., Cialdini, R. B., Miller, G. F., & Kenrick, D. T. (2007). Blatant Benevolence and Conspicuous Consumption: When Romantic Motives Elicit Costly Signals. *Journal of Personality and Social Psychology*, 93(1), 85-102.
- Groeger, J. A. (2000). *Understanding driving: applying cognitive psychology to a complex everyday task*. Hove, England: Psychology Press.
- Groeger, J. A., Carsten, O. M. J., Blana, E., & Jamson, H. (1999). Speed and distance estimation under simulated conditions. In A. G. Gale, I. D. Brown, C. M. Haslegrave & S. P. Taylor (Eds.), *Vision in Vehicles VII*. Amsterdam, Netherlands: Elsevier.
- Groen, E. L. & Bles, W. (2004). How to use body tilt for the simulation of linear self motion. *Journal of Vestibular Research*, 14, 375-385.

- Groh, J. M., Born, R. T., & Newsome, W. T. (1997). How is a sensory map read out? Effects of microstimulation in visual area MT on saccades and smooth pursuit eyes movements. *Journal of Neuroscience*, 17, 4312-4330.
- Grubb, E., & Stern, B. (1971). Self-Concept and Significant Others. *Journal of Marketing Research*, 8(3), 382-385.
- Guilford, J. P. (1954). *Psychometric Methods*. New York, NY: McGraw-Hill.
- Guinness, P. (2005). *Beasts from the East: Japan's ultimate performance cars*. Sparkford, England: Haynes & Co.
- Hackbarth, A., & Madlener, R. (2013). Consumer preferences for alternative fuel vehicles: A discrete choice analysis. *Transportation Research Part D: Transport and Environment*, 25, 5-17.
- Halliday, T. (1992). *The Senses and Communication*. Milton Keynes, England: Open University Press.
- Hammett, S. T., Champion, R. A., Thompson, P. G., & Morland, A. B. (2006). Perceptual distortions of speed at low luminance: Evidence inconsistent with a Bayesian account of speed encoding. *Vision Research*, 47, 564-568.
- Hammett, S. T. Thompson, P. G., & Bedingham, S. (2000). The dynamics of velocity adaptation in human vision. *Current Biology*, 10, R882.
- Hare, W. (1997). *Fossil fuels and climate protection: the carbon logic*. Amsterdam, Netherlands: Greenpeace International.
- Harms, L. (1991). Variation in drivers' cognitive load. Effects of driving through village areas and rural junctions. *Ergonomics*, 34, 151-160.
- Harms, L. (1996). Driving performance on a real road and in a driving simulator: results of a validation study. In A.G. Gale, I.D. Brown, C.M. Haslegrave & S.P. Taylor (Eds.) *Vision in Vehicles V*. Amsterdam, Netherlands: Elsevier.

Hassin, R. R., Uleman, J. S., & Bargh, J. A. (2005). *The New Unconscious*. Oxford, England: Oxford University Press.

Heath, A., & Scott, D. (1998). The Self-Concept and Image Congruence Hypothesis: An Empirical Evaluation in the Motor Vehicle Market. *European Journal of Marketing*, 32(11/12), 1110-1123.

Heffner, R., Kurani, K.S., & Turrentine, T.S. (2007). Symbolism in California's early market for hybrid electric vehicles. *Transportation Research D: Transport & Environment*, 12, 396-413.

Heine, K. (2009). Using Personal and Online Repertory Grid Methods for the Development of a Luxury Brand Personality. *Electronic Journal of Business Research Methods*, 7(1). Retrieved from: <http://www.ejbrm.com/issue/download.html?idArticle=199>

Heitanen, M. A., Crowder, N. A., & Ibbotson, M.R. (2008). Contrast gain control is drift-dependent: An informational analysis. *Journal of Neurophysiology*, 97, 1078-1087.

Hewstone, M. (1989). *Causal Attribution: From Cognitive Processes to Collective Beliefs*. Oxford, England: Blackwell.

Hirschman, E. C. & Holbrook, M. B. (1982). Hedonic Consumption: Emerging Concepts, Methods and Propositions. *Journal of Marketing*, 46, 92-101.

Hiscock, R., Macintyre, S., Kearns, A., & Ellaway, A. (2002). Means of transport and ontological security: Do cars provide psycho-social benefits to their users? *Transportation Research Part D: Transport & Environment*, 7, 119-135.

Hoeffler, S. (2003). Measuring Preferences for Really New Products. *Journal of Marketing Research*, XL, 406-420.

Hoffman, J. D., Brown, T. L., Lee, J. D., & McGehee, D. V. (2002). Comparisons of braking in a high fidelity simulator to braking on a test track. *Transportation Research Record*, 1803, 59-65.

- Holbrook, M. B., & Hirschman, E. C. (1993). *The Semiotics of Consumption: Interpreting Symbolic Consumer Behavior in Popular Culture and Works of Art*. New York, NY: Mouton de Gruyter.
- Horswill, M. S., & McKenna, F. P. (1999). The development, validation, and application of a video-based technique for measuring an everyday risk-taking behaviour: drivers' speed choice. *Journal of Applied Psychology*, 84, 977-985.
- Horswill, M. S., & Plooy, A. M. (2008a). Auditory feedback influences perceived driving speeds. *Perception*, 37, 1037-1043.
- Horswill, M. S. & Plooy, A. M. (2008b). Reducing contrast makes speeds in a video-based driving simulator harder to discriminate as well as making them appear slower. *Perception*, 37, 1269-1275.
- Hurlimann, F., Kiper, D. C., & Carandini, M. (2002). Testing the Bayesian model of perceived speed. *Vision Research*, 42, 2253-2257.
- International Energy Agency (2009). *Transport Energy and CO₂: Moving Towards Sustainability*. Paris, International Energy Agency.
- Irving, A. (1973). *The Perceptual Problems of the Driver*. Report of the 1st Congress of I.D.B.R.A., Zurich.
- Jamson, A. H. (1999). Curve negotiation in the Leeds driving simulator: the role of driver experience. In D. Harris (Ed.), *Engineering in Psychology and Cognitive Ergonomics*. Farnham, England: Ashgate.
- Jankowicz, D. (2004). *The Easy Guide to Repertory Grids*. Chichester, England: Wiley.
- Jantos, J., Brol, S., & Mamala, J. (2007). Problems in Assessing Road Vehicle Driveability Parameters Determined with the Aid of Accelerometer. *SAE Technical Papers Series*, 2007-01-1473. Warrendale, PA., Society of Automotive Engineers.

- Jeekel, H. (2003). *The Car-dependent Society: A European Perspective*. Farnham, England: Ashgate.
- Jensen, A. F., Cherchi, E., & Mabit, S. L. (2013). On the stability of preferences and attitudes before and after experiencing an electric vehicle. *Transportation Research Part D: Transport and Environment*, 25, 24-32.
- Jeon, B., Ajovalasit, M., & Giacomini, J. (2009). Effects of gender differences on the subjective perceived intensity of steering wheel rotational vibration based on a multivariate regression model. *International Journal of Industrial Ergonomics*, 39(5), 736-743.
- Jewitt, C. H., Gibbs, L. M., & Evans, B. (2005). Gasoline Driveability Index, Ethanol Content and Cold Start/Warm-Up Performance. *SAE Technical Papers Series, 2005-01-3864*. Warrendale, PA., Society of Automotive Engineers.
- Jonah, B. A. (1997). Sensation seeking and risky driving: a review and synthesis of the literature. *Accident Analysis and Prevention*, 29, 651-665.
- Jones, E. E., & Davis, K. E. (1965). From acts to dispositions: the attribution process in person perception. In L. Berkowitz (Ed), *Advances in Experimental Social Psychology, Vol. 2*. New York, NY: Academic Press.
- Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica*, 47, 263-291.
- Kahneman, D., & Tversky, A. (2000). *Choices, Values and Frames*. Cambridge, England: Cambridge University Press.
- Kaplan, H. S., & Gangestad, S. W. (2005). Life History and Evolutionary Psychology. In D. M. Buss (Ed.), *The Handbook of Evolutionary Psychology*. Hoboken, NJ: Wiley.
- Kaptein, N. A., Theeuwes, J., & Van Der Horst, R. (1996). Driving Simulator Validity: Some Considerations. *Transportation Research Record*, 1550, 30-36.

- Kaptein, N. A., van der Horst, A. R. A., & Hoekstra, W. (1996). *Visual Information in a Driving Simulator: A Study on Braking Behavior and Time-to-Collision*. Soesterberg, Netherlands: TNO Human Factors Research Institute.
- Keegan, S. (2006). Qualitative research: emerging from the cocoon of science. *The Psychologist*, 19(11), 668-671.
- Keller, K. (1993). Conceptualizing, Measuring, and Managing Customer-Based Brand Equity. *Journal of Marketing*, 57 (1), 1-22.
- Kelley, H. H. (1967). Attribution theory in social psychology. In D. Levine (Ed.), *Nebraska Symposium on Motivation, Vol. 15*. Lincoln, NE: University of Nebraska Press.
- Kelly, G. A. (1955). *A theory of personality: the psychology of personal constructs*. New York, NY: Norton.
- Kemeny, A., & Panerai, F. (2003). Evaluating perception in driving simulation experiments. *Trends in Cognitive Science*, 7(1), 31-37.
- Kennedy, J., Gorell, R., Crinson, L., Wheeler, A., & Elliott, M. (2005). 'Psychological' traffic calming. *TRL Report TRL641*. Crowthorne, England: Transport Research Laboratory.
- Kenrick, D. T., Griskevicius, V., Neuberg, S. L., & Schaller, M. (2010). Renovating the Pyramid of Needs: Contemporary Extensions Built Upon Ancient Foundations. *Perspectives on Psychological Science*, 5(3), 292-314.
- Kersten, D. (1990). Statistical limits to image understanding. In C. Blakemore (Ed.), *Vision: Coding and Efficiency*. Cambridge, England: Cambridge University Press.
- Kiessling, D. (1993). Artificially Induced Drivability Malfunctions Improve Value of Rater Round Robin Exercises. *Fourth International Symposium on the performance evaluation of automotive fuels and lubricants*, Birmingham, UK.
- King, J. (2007). *The King Review of low-carbon cars*. Norwich, England: HMSO.

- Kinoshita, S., & Lupker, S. J. (2003). *Masked Priming: The State of the Art*. Hove, England: Psychology Press.
- Klauer, K. C., & Musch, J. (2003). Affective Priming: Findings and Theories. In J. Musch & K. C. Klauer (Eds.), *The Psychology of Evaluation. Affective Processes in Cognition and Emotion*. Mahwah, NJ.: Lawrence Erlbaum.
- Klockner, C. A., Nayum, A., & Mehmetoglu, M. (2013). Positive and negative spillover effects from electric car purchase to car use. *Transportation Research Part D: Transport and Environment*, 21, 32-38.
- Knill, D. C., & Kersten, D. (1991). Learning a near-optimal estimator for surface shape from shading. *Computer Vision, Graphics and Image Processing*, 50, 75-100.
- Knill, D. C., & Richards, W. (Eds.) (1996). *Perception as Bayesian Inference*. Cambridge, England: Cambridge University Press.
- Koca, S. (2010). *Transition to Hydrogen Fuel Cell Vehicles: Energy Policies, Politics and Prices*. Hauppauge, NY: Nova Sciences Publishers.
- Kono, N., Fukumoto, J., Iizuka, M., & Takeda, H. (2006). Influence of FAME Blends in Diesel Fuel on Drivability Performance of Diesel Vehicles at Low Temperatures. *SAE Technical Papers Series, 2006-01-3306*. Warrendale, PA.: Society of Automotive Engineers.
- Kramer, R. S. S., & Ward, R. (2010). Internal facial features are signals of personality and health. *Quarterly Journal of Experimental Psychology*, 63, 2273-2287.
- Krekelberg, B., van Wezel, R. J. & Albright, T. D. (2006). Adaptation in macaque MT reduces perceived speed and improves speed discrimination. *Journal of Neurophysiology*, 95, 8988-8998.
- Kruglanski, A. W., Shah, J. Y., Fishbach, A., Friedman, R., Chun, W.Y., & Sleeth-Keppler, W. (2002). A theory of goal systems. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology*, 34, 331-378. San Diego, CA: Academic Press.

- Lajunen, T. (1997). Personality and accident liability: are extraversion, neuroticism and psychoticism related to traffic and occupational fatalities? *Personality and Individual Differences*, 31, 1365-1276.
- Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences*, 23(11), 571-579.
- Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences*, 7(1), 12-18.
- Lamme, V. A. F., Zipser, K., & Spekreijse, H. (2002). Masking interrupts figure-ground signals in V1. *Journal of Cognitive Neuroscience*, 14, 1044-1053.
- Lane, B. (2011). *Market delivery of ultra-low carbon vehicles in the UK: An evidence review for the RAC Foundation*. Retrieved from:
http://design.open.ac.uk/documents/Market_delivery_of_UCLVs_in_the_UK-Ecolane.pdf
- Lane, K. A., Banaji, M. R., Nosek, B. A., & Greenwald, A.G. (2007). Understanding and Using the Implicit Association Test: What We Know (So Far) about the Method. In B. Wittenbrink & N. Schwarz (Eds.), *Implicit Measures of Attitudes*. New York, NY: Guilford Press.
- Langdrige, D. (2007). *Phenomenological Psychology: Theory, Research and Method*. Harlow, England: Pearson.
- Lebeau, K., van Mierlo, J., Lebeau, P., Mairesse, O., & Macharis, C. (2012). The market potential for plug-in hybrid and battery electric vehicles in Flanders: A choice-based conjoint analysis. *Transportation Research Part D: Transport and Environment*, 17, 592-597.
- Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception*, 5, 437-459.
- Lee, J., & Shrum, L. J. (2012). Conspicuous Consumption versus Charitable Behavior in Response to Social Exclusion: A Differential Needs Explanation. *Journal of Consumer Research*, 39, 530-544.

- Leffingwell, R., Holmstrom, D., & Newhardt, D. (2008). *Muscle, America's Legendary Performance Cars*. Minneapolis, MN.: Motorbooks.
- Lewis-Evans, B., & Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention*, 38(3), 610-617.
- Liberman, M., Trope, Y., & Stephan, E. (2007). Psychological Distance. In A.W. Kruglanski & E.T. Higgins (Eds.), *Social Psychology: Handbook of basic principles*. New York, NY: Guilford Press.
- Liebert, R.M., & Liebert, L.L. (1998). *Liebert & Speigler's Personality: Strategies & Issues*. Pacific Grove, CA.: Brookes/Cole Publishing Company.
- Lieven, T., Muhlmeier, S., Henkel, S., & Waller, J. F. (2011). Who will buy electric cars? An empirical study in Germany. *Transportation Research Part D: Transport and Environment*, 16, 236-243.
- Ligas, M. (2000). People, Products and Pursuits: Exploring the Relationship Between Consumer Goals and Product Meanings. *Psychology and Marketing*, 17 (11), 983-1003.
- Lisberger, S. G., Morris, E. J., & Tychsen, L. (1987). Visual motion processing and sensory-motor integration for smooth pursuit eye movements. *Annual Review of Neuroscience*, 10, 97-129.
- Lisberger, S. G., & Movshon, J. A. (1999). Visual motion analysis for pursuit of eye movements in area MT of macaque monkeys. *Journal of Neuroscience*, 19, 2224-2246.
- List, H. O., & Schoegg, P. (1998). Objective Evaluation of Vehicle Driveability. *SAE Technical Papers Series, 980204*. Warrendale, PA.: Society of Automotive Engineers.
- Little, A. C., & Perrett, D. I. (2007). Using composite images to assess accuracy in personality attribution to faces. *British Journal of Psychology*, 98, 111-126.
- Liu, J., & Newsome, W. T. (2005). Correlation between speed perception and neural activity in the middle temporal visual area. *Journal of Neuroscience*, 25, 711-722.

- Lockwood, C. R. (1997). *Using the TRL driving simulator to evaluate traffic calming measures*. TRL Report TRL245, Crowthorne, England: TRL Limited.
- MacNeilage, P. R., Banks, M. S., Berger, D. R., & Bulthoff, H. H. (2007). A Bayesian model of the disambiguation of gravito-inertial force by visual cues. *Experimental Brain Research*, 179, 263-290.
- Maloney, L. T., & Landy, M. S. (1989). A statistical framework for robust fusion of depth information. *Proceedings of the SPIE: Visual Communications and Image Processing, Part 2*, 1154-1163.
- Malterre, G. (1977). *Regulation de la vitesse a l'approche de points singuliers*. Rapport de recherche, Arcueil, ONSER.
- Mann, E. & Abraham, C. (2006). The role of affect in UK commuters' travel mode choices: an interpretive phenomenological analysis. *British Journal of Psychology*, 97, 155-176.
- Manser, M. P., & Hancock, P. A. (2007). The influence of perceptual speed regulation on speed perception, choice and control: Tunnel wall characteristics and influences. *Accident Analysis and Prevention*, 39, 69-78.
- Marsden, D., & Littler, D. (1998). Repertory Grid Technique: An interpretive research framework. *European Journal of Marketing*, 34(7), 816-834.
- Marr, D. (1982). *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. New York, NY: W.H. Freeman & Company.
- Marr, D., & Hildreth, E. (1980). Theory of edge detection. *Proceedings of the Royal Society of London, Series B*, 207, 187-217.
- Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, 50, 370-396.
- Matthews, H. D., Gillet, N. P., Stott, P. A., & Zickfeld, K. (2009). The proportionality of global warming to cumulative carbon emissions. *Nature*, 459, 829-833.

Matthews, H., & Caldeira, K. (2008). Stabilizing climate requires near-zero emissions. *Geophysical Research Letters*, 35, L04705.

Matthews, M. L., & Cousins, L. R. (1980). The influence of vehicle type on the estimation of velocity when driving. *Ergonomics*, 23, 1151-1160.

Matthews, R., Buss, R., Stanley, W., Blanchard-Fields, F., Cho, J., & Druhan, B. (1989). Role of implicit and explicit processes in learning from examples: A synergistic effect. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 15, 1083-1100.

Matthews, R. C., & Roussel, L. G. (1997). Abstractness of implicit knowledge: A cognitive evolutionary perspective. In D. C. Berry (Ed.), *How Implicit is Implicit Learning?* Oxford, England: Oxford University Press.

McAdams, S., & Bigand, E. (1993). *Thinking in Sound: The Cognitive Psychology of Human Audition*. Oxford, England: Oxford University Press.

McArraragher, S., Thompson, N., Bazzani, R., Aarnink, T., Kwon, Y., Martinez, P. M., Zemroch, P. J., et al. (2004). CONCAWE/GFC Study on Gasoline Volatility an Ethanol Effects on Hot and Cold Weather Driveability of Modern European Vehicles. *SAE Technical Papers Series, 2004-01-2002*. Warrendale, PA., Society of Automotive Engineers.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception. Part 1. An account of basic findings. *Psychology Review*, 88, 375-407.

McCracken, G. (1988). *Culture and Consumption*. Bloomington, IN: Indiana University Press.

McCrae, R. R., & Costa, P. T. (2003). *Personality in Adulthood: A Five-Factor Theory Perspective*, New York, NY: Guilford Press.

McCrae, R. R., & Costa, P. T. (2004). A contemplated revision of the NEO Five-Factor Inventory. *Personality and Individual Differences*, 36(3), 587-596.

- McCrae R. R., Costa P. T., & Martin T. A. (2005). The NEO-PI-3: A more readable revised NEO personality inventory. *Journal of Personality Assessment*, 84 (3), 261–270.
- McLane, R. C., & Wierwille, W. W. (1975). The influence of motion and audio cues on driver performance in an automobile simulator. *Human Factors*, 17, 488-501.
- McLeod, P., & Dienes, Z. (1996). Do fielders know where to go to catch the ball or only how to get there? *Journal of Experimental Psychology: Human Perception and Performance*, 22, 531–543.
- McLeod, P., Reed, N., & Dienes, Z. (2001). Towards a unified fielder theory: What we do not yet know about how fielders run to catch the ball. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 1347–1355.
- McNamara, T. P. (1992). Theories of priming: I. Associative distance and lag. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 1173-1190.
- McNamara, T. P. (2005). *Semantic priming: perspectives from memory and word recognition*. Hove, England: Psychology Press.
- Mead, N. L., Baumeister, R. F., Stillman, T. F., Rawn, C. D., & Vohs, K. D. (2010). Social Exclusion Causes People to Spend and Consume Strategically in the Service of Affiliation. *Journal of Consumer Research*, 37, 902-919.
- Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., et al. (2009). Greenhouse-gas emission targets for limiting global warming to 2 °C. *Nature*, 458, 1158-1163.
- Meyer, D. E., Schvaneveldt, R. W., & Ruddy, M. G. (1975). Loci of contextual effects on visual word recognition. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and Performance: V* (pp. 98-118). New York, NY: Academic Press.
- Mick, D. G. (1986). Consumer Research and Semiotics: Exploring the Morphology of Signs, Symbols, and Significance. *Journal of Consumer Research*, 13, 196-213.
- Miller, D. (2010). *Stuff*. Cambridge, England: Polity Press.

- Miller, G. A. (1969). *The psychology of communication: seven essays*. New York, NY: Basic Books.
- Miller, G. A., Galanter, E., & Pribram, K. H. (1960). *Plans and the structure of behavior*. New York, NY: Holt, Reinhart & Winston.
- Miller, G. (2000). *The Mating Mind: How sexual choice shaped the evolution of human nature*. London, England: Heinemann.
- Miller, G. (2009) *Spent. Sex, Evolution and Consumer Behaviour*. New York, NY: Viking.
- Millis, K. K., & Neimeyer, R. A. (1990). A test of the dichotomy corollary: propositions versus constructs as basic cognitive units, *International Journal of Personal Construct Psychology*, 3, 167-181.
- Mo, C. Y., Beaumont, A. J., & Powell, N. N. (1996). Active Control of Driveability. *SAE Technical Papers Series, 960046*. Warrendale, PA: Society of Automotive Engineers.
- Moore, B. C. (2001). Basic Auditory Processes, in E.B. Goldstein (Ed.), *Blackwell Handbook of Perception*. Oxford, England: Blackwell.
- Moskowitz, G. B., & Grant, H. (2009). Introduction. In G. B. Moskowitz & H. Grant (Eds.), *The Psychology of Goals*. New York, NY: Guilford Press.
- Musch, J., & Klauer, K. C. (2003). *The Psychology of Evaluation. Affective Processes in Cognition and Emotion*. Mahwah, NJ.: Lawrence Erlbaum.
- Näätänen, R., & Summala, H. (1974). A model for the role of motivational factors in drivers' decision making. *Accident Analysis and Prevention*, 6, 243-261.
- Näätänen, R., & Summala, H. (1976). *Road-user behavior and traffic accidents*. Amsterdam, Netherlands: Elsevier.
- Neal, A., & Hesketh, B. (1997). Episodic knowledge and implicit learning. *Psychonomic Bulletin and Review*, 4, 24-37.

- Neely, J. H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. *Memory and Cognition*, 4(5), 648-654.
- Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology, General*, 106, 226-254.
- Nehaoua, L., Arioui, H., Espie, S., & Mohellebi, H. (2006). Motion Cueing Algorithms for Small Driving Simulator. *Proceedings of the 2006 International Conference on Robotics and Automation*, Orlando, FL.
- Neisser, U. (1994). Multiple systems: a new approach to cognitive theory. *European Journal of Cognitive Psychology*, 6(3), 225-241.
- Nelissen, R. M. A., & Meijers, M. H. C. (2011). Social benefits of luxury brands as costly signals of wealth and status. *Evolution and Human Behavior*, 32, 343-355.
- Nettle, D. (2007). *Personality*, Oxford, England: Oxford University Press.
- Nettle, D., & Clegg, H. (2007). Personality, Mating Strategies, and Mating Intelligence. In G. Geher & G. Miller (Eds.), *Mating Intelligence*. Hove, England: Psychology Press.
- Newsome, W. T. & Pare, E. B. (1988). A selective impairment of motion perception following lesions of the middle temporal visual area (MT). *Journal of Neuroscience*, 8, 2201-2211.
- Newsome, W. T., Shadlen, M. N., Zohary, E., Britten, K. H. & Movshon, J. A. (1995). Visual motion: Linking neuronal activity to psycho-physical performance. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences*. Cambridge, MA.: MIT Press.
- Ni Dhiomasaigh, L. & McCarthy, J. (1995). An exploration of implicit and explicit learning and skill level in complex dynamic systems. *Irish Journal of Psychology*, 16 (4), 322-333.
- Nichols, M. J., & Newsome, W.T. (2002). Middle temporal visual area microstimulation influences veridical judgements of motion direction. *Journal of Neuroscience*, 22, 9530-9540.

- Norman, J. (2001). Ecological psychology and the two visual systems: not to worry. *Ecological Psychology*, 13(2), 135-145.
- Norman, J. (2002). Two visual systems and two theories of perception: an attempt to reconcile the constructivist and ecological approaches. *Behavioural and Brain Sciences*, 25(1), 73-96.
- Organization for Economic Co-Operation and Development (OECD) (2004). *Biofuels for Transport: An International Perspective*. Paris, France: OECD Publishing.
- Olah, G., Goeppert, A., & Prakash, G. K. S. (2006). *Beyond Oil and Gas: The Methanol Economy*. New York, NY: Wiley.
- Overgaard, M., Timmermans, B., Sandberg, K., & Cleeremans, A. (2010). Optimizing subjective measures of consciousness. *Consciousness and Cognition*, 19, 682-684.
- Ozkan, T., Lajenen, T., Chliaoutakis, J.L., Parker, D., & Summala, H. (2006). Cross-cultural differences in driving behaviours: A comparison of six countries. *Transportation Research Part F: Traffic Psychology & Behaviour*, 9, 227-242.
- Pachauri, R. K., & Reisinger, A. (Eds.) (2007). *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.
- Park, C. W., Jaworski, B., & MacInnis, D. (1986). Strategic Brand Concept-Image Management, *Journal of Marketing*, 50, 135-145.
- Parker's Guide (2010): <http://www.parkers.co.uk> , accessed on 20/4/2010.
- Palmer, S. E. (1999). *Vision Science: Photons to Phenomenology*. Cambridge, MA.: MIT Press.
- Passmore, M. A., Patel, A., & Lorentzen, R. (2001). The influence of engine demand map design on vehicle perceived performance. *International Journal of Vehicle Design*, 26(5), 509-522.
- Penn, D. J. (2003). The evolutionary roots of our environmental problems: Towards a Darwinian ecology. *Quarterly Review of Biology*, 78, 275-301.

- Percher, D., & Raaijmakers, J. G. W. (1999). Automatic priming effects for new associations in lexical decision and perceptual identification. *Quarterly Journal of Experimental Psychology*, 52A, 593-614.
- Pierce, C. S. (1931). *Collected Papers*. Cambridge, MA: Harvard University Press.
- Pike, G., & Edgar, G. (2005). Perception. In N. Braisby & A. Gellatly (Eds.), *Cognitive Psychology*. Oxford, England: Oxford University Press.
- Posner, M. I., & Snyder, C. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp.55-85). Hillsdale, NJ: Erlbaum.
- Powers, W. T. (2005). *Behavior: the control of perception (2nd edition)*. New Canaan, CT: Benchmark Publications.
- Price, N. S. C., Ono, S., Mustari, M. J., & Ibbotson, M.R. (2005). Comparing Acceleration and Speed Tuning in Macaque MT: Physiology and Modeling. *Journal of Neurophysiology*, 94, 3451-3464.
- Puchta, C., & Potter, J. (2004). *Focus Group Practice*. London, England: Sage.
- Puttaswamaiah, K. (2002). *Econometric Models: Techniques and Applications*. New Dehli, India: Indus Publishing Company.
- Rammstedt, B., & John, O. P. (2007). Measuring personality in one minute or less. A 10-item short version of the Big Five Inventory in English and German. *Journal of Research in Personality*, 41(1), 203-212.
- Rao, S. C., Rainer, G., & Miller, E.K. (1997). Integration of what and where in the primate prefrontal cortex. *Science*, 276, 821-824.
- Reason, J., Manstead, A., Stradling, S., Baxter, J., & Campbell, K. (1990). Errors and violations on the roads: a real distinction? *Ergonomics*, 33, 1315-1332.

- Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, 6, 855-863.
- Reber, A. S. (1976). Implicit learning of synthetic languages: The role of instructional set. *Journal of Experimental Psychology: Human Learning and Memory*, 2, 88-94.
- Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General*, 118, 219-235.
- Reber, A. S. (1993). *Implicit Learning and Tacit Knowledge: An Essay on the Cognitive Unconscious*. Oxford, England: Oxford University Press.
- Recarte, M. A., & Nunes, L. M. (1996). Perception of speed in an automobile: Estimation and production. *Journal of Experimental Psychology: Applied*, 2(4), 291-304.
- Redshaw, S. (2008). *In the Company of Cars: Driving as a Social and Cultural Practice*. Aldershot, England: Ashgate.
- Reed, M. P., & Green, P. S. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics*, 42(8), 1015-1037.
- Reed, N., McLeod, P., & Dienes, Z. (2010). Implicit knowledge and motor skill: What people who know how to catch don't know. *Consciousness & Cognition*, 19, 63-76.
- Rees, C. (2005). *A-Z Japanese Performance Cars*. Beaworthy, England: Herridge & Sons Ltd.
- Reijnders, L., & Huijbregts, M. (2009). *Biofuels for Road Transport: A Seed to Wheel Perspective*. Berlin, Germany: Springer.
- Reimann, R. (1990). The bipolarity of personal constructs. *International Journal of Personal Construct Psychology* 3, 149-165.
- Reymond, G., Droulez, J., & Kemeny, A. (2002). Visuovestibular perception of self-motion modelled as a dynamic optimization process. *Biological Cybernetics*, 87, 301-314.

- Reymond, G., & Kemeny, A. (2000). Motion Cueing in the Renault Driving Simulator. *Vehicle System Dynamics*, 34, 249-259.
- Richins, M. L. (2011). Materialism, Transformation Expectations, and Spending: Implications for Credit Use. *Journal of Public Policy & Marketing*, 30(2), 141-156.
- Riemersma, J. B. J., van der Horst, A. R. A., Hoekstra, W., Alink, G. M. M., & Otten, N. (1990). The Validity of a Driving Simulator in Evaluating Speed-Reducing Measures. *Traffic Engineering and Control*, 31(7), 416-420.
- Rifkin, J. (2002). *The Hydrogen Economy*. Cambridge, England: Polity Press.
- Rimmo, P.-A., & Aberg, L. (1999). On the distinction between violations and errors: sensation seeking associations, *Transportation Research F: Traffic Psychology and Behaviour*, 2, 151-166.
- Robson, C. (2002). *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*, 2nd Edition. Oxford, England: Blackwell.
- Rock, I. (1977). In defense of unconscious interference. In W. Epstein (Ed.), *Stability and Constancy in Visual Perception: Mechanisms and Processes*. New York, NY: Wiley.
- Rock, I. (1983). *The Logic of Perception*. Cambridge, MA.: MIT Press.
- Rock, I. (1997). *Indirect Perception*. Cambridge, MA.: MIT Press.
- Rock, P. B., Harris, M. G., & Yates, T. (2006). A Test of the Tau-Dot Hypothesis of Braking Control in the Real World. *Journal of Experimental Psychology: Human Perception and Performance*, 32 (6), 1479-1484.
- Rogers, B., & Ryals, L. (2007). Using Repertory Grid to access the underlying realities in key account relationships. *International Journal of Market Research*, 49(5), 595-612.
- Rogers, E. (2003). *Diffusion of Innovations* (5th Ed.). Free Press, New York.

- Roney, J. R. (2003). Effects of Visual Exposure to the Opposite Sex: Cognitive Aspects of Mate Attraction in Human Males. *Personality and Social Psychology Bulletin*, 29(3), 393-404.
- Rucker, D. D., & Galinsky, A. D. (2008). Desire to Acquire: Powerlessness and Compensatory Consumption. *Journal of Consumer Research*, 35, 257-267.
- Rucker, D. D., & Galinsky, A. D. (2009). Conspicuous consumption versus utilitarian ideals: How different levels of power shape consumer behavior. *Journal of Experimental Social Psychology*, 45, 549-555.
- Saad, G. (2007). *The evolutionary bases of consumption*. London, England. Psychology Press.
- Saad, G., & Vongas, J. G. (2009). The effect of conspicuous consumption on men's testosterone levels. *Organizational Behavior and Human Decision Processes*, 110, 80-92.
- Salmon, P. (2003). A psychology for teachers. In F. Fransella (Ed.), *International Handbook of Personal Construct Psychology*. New York, NY: Wiley.
- Saussure, F. De (1916). *Cours de linguistique generale*. Paris, France: Payot. R. Harris (Trans.) (1983). *Course in general linguistics*. London, England: Duckworth.
- Schmidt, F., & Tiffin, J. (1967). Distortion of Drivers' Estimates of Automobile Speed as a Function of Speed Adaptation. *Journal of Applied Psychology*, 53, 536-539.
- Schoeggl, P., Ramschak, E., & Bogner, E. (2001). On-Board Optimization of Driveability Character Depending on Driver Style by Using a New Closed Loop Approach. *SAE Technical Papers Series, 2001-01-0556*. Warrendale, PA., Society of Automotive Engineers.
- Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, 48, 39-49.
- Schwarzer, R., & Born, A. (1997). Optimistic self-beliefs: Assessment of general perceived self-efficacy in thirteen cultures. *World Psychology*, 3(1-2), 177-190.

- Seidman, S.H. (2008). Translational motion perception and vestibuloocular responses in the absence of non-inertial cues. *Experimental Brain Research*, 184, 13-29.
- Seidman, S. H., Telford, L., & Paige, G. D. (1998). Tilt perception during dynamic linear acceleration. *Experimental Brain Research*, 119, 307-314.
- Sekuler, R., & Blake, R. (2002). *Perception*, 4th Edition. New York, NY: McGraw-Hill.
- Sewell, K. W. (2003). An approach to post-traumatic stress. In F. Fransella (Ed.), *International Handbook of Personal Construct Psychology*, 223-231. Chichester, England: Wiley.
- Shackleford, T. K., Schmitt, D. P., & Buss, D. M. (2005). Universal dimensions of human mate preferences. *Personality and Individual Differences*, 39, 447-458.
- Shanks, D. (2004). Implicit Learning. In K. Lamberts & R. Goldstone (Eds.), *Handbook of Cognition*. Thousand Oaks, CA: Sage.
- Shanks, D., & St. John, M. (1994). Characteristics of dissociable human learning systems. *Behavioural and Brain Sciences*, 17, 367-395.
- Shaw, M. L. G. (Ed.) (1980). *On Becoming a Personal Scientist: interactive elicitation of personal models of the world*. London, England: Academic Press.
- Shin, J., Hong, J., Jeong, G., & Lee, J. (2012). Impact of electric vehicles on existing car usage: A mixed multiple discrete-continuous extreme value model approach. *Transportation Research Part D: Transport and Environment*, 17, 138-144.
- Shinar, D., Rockwell, T. H., & Maleki, J. A. (1980). The Effects of Changes in Driver Perception on Rural Curve Negotiation, *Ergonomics*, 23, 263-275.
- Shove, E. (2003). *Comfort, Cleanliness & Convenience: The Social Organization of Normality*. Oxford, England: Berg.
- Shove, E., Watson, M., Hand, M., & Ingram, J. (2007). *The Design of Everyday Life*. Oxford, England: Berg.

- Shrum, L. J., Wong, N., Arif, F., Chugani, S. K., Gunz, A., Lowrey, T. M., et al. (2013). Reconceptualizing materialism as identity goal pursuits: Functions, processes, and consequences. *Journal of Business Research*, 66, 1179-1185.
- Siegel, J. T. (2011). Dying for romance: Risk taking as purposive behavior. *Psychology, Health & Medicine*, 16 (6), 719-726.
- Sirgy, M. J. (1982a). Self-Image/Product-Image Congruity and Advertising Strategy. In V. Kothari (Ed.), *Developments in Marketing Science, Volume 5*. (pp.129-133). Marquette, MI: Academy of Marketing Science.
- Sirgy, M. J. (1982b). Self-Concept in Consumer Behaviour: A Critical Review. *Journal of Consumer Research*, 9(3), 287-301.
- Sirgy, M. J. (1985). Using Self-Congruity and Ideal Congruity to Predict Purchase Motivation. *Journal of Business Research*, 13(3), 195-206.
- Sirgy, M. J., & Danes, J. E. (1981). Self-image/product-image congruence models. In A. Mitchell (Ed.), *Advances in Consumer Research, Volume 9*. Ann Arbor, MI: Association for Consumer Research.
- Simpson, J. A., & Gangestad, S. W. (1992). Sociosexuality and Romantic Partner Choice. *Journal of Personality*, 60(1), 31-51.
- Sivak, M. (1996). The information that drivers use: is it indeed 90% visual? *Perception*, 25, 1081-1089.
- Skippon, S.M. (2014). How consumer drivers construe vehicle performance: implications for the uptake of electric vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, 23, 15-31.
- Skippon, S. M., Diels, C., & Reed, N. (2012). Driving style as a fitness indicator. In L. Dorn (Ed.), *Driver Behaviour and Training Vol. V*. Farnham, England: Ashgate.

- Skippon, S., & Garwood, M. (2011). Responses to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. *Transportation Research Part D: Transport and Environment*, 16, 525-531.
- Skippon, S.M., Reed, N., Luke, T., Robbins, R., Chattington, M., & Harrison, A.H. (2010). Relationships between driving style, Self-Reported Driving Behaviour and Personality. In L. Dorn (Ed.) *Driver Behaviour and Training Vol. IV*. Farnham, England: Ashgate.
- Skippon, S. M., Vannozzi, T., & Flack, J. (2013). Driving as the simultaneous pursuit of multiple goals. *Sixth International Conference on Driver Behaviour and Training*, Helsinki, Finland.
- Skippon, S. M., Veeraraghavan, S., Ma, H., Gadd, P., & Tait, N. (2012). Combining technology development and behaviour change to meet CO₂ cumulative emission budgets for road transport: Case studies for the USA and Europe. *Transportation Research Part A: Policy and Practice*, 46, 1405-1423.
- Smith, J. A., Flowers, P., & Larkin, M. (2009). *Interpretative Phenomenological Analysis: Theory, Methods and Research*. London, England: Sage.
- Solomon, M. (1982). The Role of Products as Social Stimuli: A Symbolic Interactionism Perspective. *Journal of Consumer Research*, 10(3), 319-329.
- Solomon, S., Plattnerb, G.-K., Knuttic, R., & Friedlingsteind, P. (2009). Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences*, 106, 1704-1709.
- Son, K., Choi, K.-H., & Yoon, J.-S. (2004). Human Sensibility Ergonomics Approach to Vehicle Simulator Based on Dynamics. *JSME International Journal*, 47(3), 889-895.
- Sperling, D., Delucchi, M. A., Davis, P. M., & Burke, A. F. (1994) *Future Drive: Electric Vehicles and Sustainable Transportation*. Washington, D.C.: Island Press.
- Sperling, D., & Gordon, D.(2009). *Two Billion Cars: Driving Towards Sustainability*. Oxford, England: Oxford University Press.

Sperling, G., & Doshier, B. A. (1986). Strategy and optimization in human information processing. In K. Boff, L. Kaufmann, & J. Thomas (Eds.), *Handbook of Human Perception and Performance*, Vol. 1. New York, NY: Wiley.

Stanley, W. B., Matthews, R., Buss, R., & Kotler-Cope, S. (1989). Insight without awareness: On the interaction of verbalisation, instruction and practice on a simulated process control task. *Quarterly Journal of Experimental Psychology*, 41, 553-577.

Stanton, N., & Young, M. S. (1999). *A Guide to Methodology in Ergonomics: Designing for Human Use*. London, England: Taylor & Francis.

Stearns, S. C., Allal, N., & Mace, R. (2008). Life History and Human Development. In C. Crawford & D. Krebs (Eds.), *Foundations of Evolutionary Psychology*. New York, NY: Lawrence Erlbaum.

Steg, L. (2005). Car Use: Lust and must. Instrumental, symbolic and affective motives for using a motor car, *Transportation Research Part A: Policy and Practice*, 39, 147-162.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, England: Cambridge University Press.

Stevens, S. S. (1975). *Psycho-physics: Introduction to Its Perceptual, Neural and Social Prospects*. New York, NY: Wiley.

Stewart, V., & Stewart, A. (1981). *Business Applications of the Repertory Grid*. London, England: McGraw-Hill.

Stewart, S., Stinnett, H., & Rosenfeld, L.B. (2000). Sex differences in desired characteristics of short-term and long-term relationship partners. *Journal of Social and Personal Relationships*, 17(6), 843-853.

Stocker, A. A., & Simoncelli, E.P. (2006). Noise characteristics and prior expectations in human visual speed perception. *Nature Neuroscience*, 9(4), 578-585.

- Strauss, A., & Corbin, J. (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, CA: Sage.
- Styles, E. A. (2005). *Attention, Perception and Memory: An Integrated Introduction*. Hove, England: Psychology Press.
- Sumer, N. (2003). Personality and behavioural predictors of traffic accidents: testing a contextual mediated model. *Accident Analysis and Prevention*, 35, 949-964.
- Sumer, N., Lajunen, T., & Ozkan, T. (2005). Big Five Personality Traits as the Distal Predictors of Road Accident Involvement, In G. Underwood, (Ed.), *Traffic and Transport Psychology: Theory and Application*. Amsterdam, Netherlands: Elsevier.
- Summala, H. (2007). Towards Understanding Motivational and Emotional Factors in Driver Behaviour: Comfort Through Satisficing. In P. C. Cacciabue (Ed.), *Modelling Driver Behaviour in Automotive Environments: Critical Issues in Driver Interactions with Intelligent Transport Systems*. London, England: Springer-Verlag London Ltd.
- Sundie, J. M., Kenrick, D. T., Griskevicius, V., Tybur, J. M., Vohs, K. D., & Beal, D. J. (2010). Peacocks, Porsches, and Thorstein Veblen: Conspicuous Consumption as a Sexual Signalling System. *Journal of Personality and Social Psychology*, 100(4), 664-680.
- Tan, F., Tung, L.-L., & Xu, Y. (2007). Surfacing Meta-categories of Web-designers' Criteria for B2C Website Evaluation: A Qualitative Study Using the Repertory Grid Technique. *11th Pacific-Asia Conference on Information Systems*. Retrieved from: <http://www.pacis-net.org/file/2007/1250.pdf>
- Taubman-Ben-Ari, O., Mikulincer, M., & Gillath, O. (2004). The multidimensional driving style inventory – scale construct and validation. *Accident Analysis and Prevention*, 36, 323-332.
- Tenkink, E., & van der Horst, A. R. A. (1991). *Effects of Road Width and Curve Characteristics on Driving Speed* (in Dutch). Report IZF 1991 C-26. Soesterberg, Netherlands: TNO Institute for Perception.

- Thompson, P. (1981). Velocity after-effects: The effects of adaptation to moving stimuli on the perception of subsequently seen moving stimuli. *Vision Research*, 21, 337-345.
- Thorgersen, J., & Garling, A. (2001). Segmenting the Market for an Environment-Friendly Automotive Innovation. *Ninth International Conference of Greening of Industry Network*, Bangkok.
- Thurstone, L. L. (1927). A law of comparative judgment. *Psychological Review*, 34, 273-286.
- Tong, S. (2009). Using IVDR to explore fuel consumption and provide driver feedback. Final Project Report PPR410, Crowthorne, Transport Research Laboratory.
- Torgerson, W. S. (1958). *Theory and Methods of Scaling*. New York, NY: Wiley.
- Törnros, J. (1998). Driving behavior in a real and a simulated road tunnel-a validation study. *Accident Analysis and Prevention*, 30(4), 497-503.
- Townsend, J. M., & Wasserman, T. (1998). Sexual attractiveness: Sex differences in assessment and criteria. *Evolution and Human Behaviour*, 19, 171-191.
- Train, K. E. (2009). *Discrete Choice Methods with Simulation*. Cambridge, England: Cambridge University Press.
- Travis, R. C., & Dodge, R. (1928). Experimental analysis of the sensorimotor consequences of passive oscillation, rotary rectilinear. *Psychological Monographs*, 38, Whole No. 175.
- Trentmann, F. (2006). *The Making of the Consumer: Knowledge, Power & Identity in the Modern World*. Oxford, England: Berg.
- Triggs, T., & Berenyi, J. S. (1982). Estimation of automobile speed under day and night conditions. *Human Factors*, 24, 111-114.
- Trivers, R. L. (1972). Parental investment and sexual selection. In B. G. Campbell (Ed.), *Sexual selection and the descent of man* (pp. 136-179). Chicago, IL: Aldine.

- Trope, Y., & Liberman, M. (2003). Temporal Construal. *Psychological Review*, 110, 403-421.
- Tucker, W. T. (1957). *Foundations for a Theory of Consumer Behavior*. New York, NY: Rinehart & Winston.
- Ulleberg, P. (2002). Personality subtypes of young drivers. Relationship to risk-taking preferences, accident involvement, and response to a traffic safety campaign. *Transportation Research Part F: Traffic Psychology and Behaviour*, 4, 279-297.
- Ulleberg, P., & Rundmo, T. (2003). Personality, attitudes and risk perception as predictors of risky driving behaviour among young drivers. *Safety Science*, 41, 427-443.
- Vaa, T. (2007). Modelling Driver Behaviour on Basis of Emotions and Feelings: Intelligent Transport Systems and Behavioural Adaptations. In P. C. Cacciabue (Ed.), *Modelling Driver Behaviour in Automotive Environments: Critical Issues in Driver Interactions with Intelligent Transport Systems*. London, England: Springer-Verlag London Ltd.
- Van der Mede, P. H. J., & van Berkum, E. C. (1993). *The Impact of Traffic Information: Dynamics in Route and Departure Time Choice*. Doctoral Thesis. Delft University of Technology, Delft, the Netherlands.
- Veblen, T. (1899). *The Theory of the Leisure Class*. New York, NY: Penguin.
- Vignoles, V. L., Regalia, C., Manzi, C., Gollege, J., & Scabini, E. (2006). Beyond Self-Esteem: Influence of Multiple Motives on Identity Construction. *Journal of Personality and Social Psychology*, 90(2), 308-333.
- Wade, N. J., & Bruce, V. (2001). Surveying the scene: 100 years of British vision. *British Journal of Psychology*, 92(1), 79-113.
- Waldorp, J. (1989). Status for Sale. *American Demographics*, 11(2), 6-8.
- Walker, B. M. (2003). Identity and travelling. In J. W. Scheer (Ed.), *Crossing Borders – Going Places*, pp. 82-92, Geissen, Germany: Psychosozial-Verlag.

- Walker, B. M., Ramsey, F. L., & Bell, R. C. (1988). Dispersed and undispersed dependency. *International Journal of Personal Construct Psychology* 1, 63-80.
- Walker, B. M., & Winter, D. A. (2007). The Elaboration of Personal Construct Psychology. *Annual Review of Psychology*, 58, 453-477.
- Waylen, A. & McKenna, F. (2002). *Cradle Attitudes – Grave Consequences. The development of gender differences in risky attitudes and behaviour in road use*. Basingstoke, England: AA Foundation for Road Safety Research.
- Wegner, D. M., & Bargh, J. A. (1998). Control and automaticity in social life. In D. T. Gilbert, S. T. Fiske, & G. Lindzey (Eds.), *The handbook of social psychology* (4th edition). Boston, MA: McGraw-Hill.
- Wei, X., Pisu, P., Rizzoni, G., & Yurkovich, S. (2003). Dynamic modeling of a hybrid electric drivetrain for fuel economy, performance and driveability evaluations. *Proceedings of 2003 ASME International Mechanical Engineering Congress*, Washington, D.C.
- Wei, X., & Rizzoni, G. (2004). Objective Metrics of Fuel Economy, Performance and Driveability – A Review. *SAE Technical Papers Series, 2004-01-1338*. Warrendale, PA.: Society of Automotive Engineers.
- Weinstein, I. (1968). Intensive and extensive aspects of tactile sensitivity as a function of body part, sex, and laterality. In D. R. Kenshalo (Ed.), *The skin senses*. Springfield, IL.: Thomas.
- Weiss, Y., Simoncelli, E. P., & Adelson, E. H. (2002). Motion illusions as optimal percepts. *Nature Neuroscience*, 5(6), 598-604.
- Wicke, V., Brace, C. J., & Vaughan, N. D. (2000). The Potential for Simulation of Driveability of CVT Vehicles. *SAE Technical Papers Series, 2000-01-0830*. Warrendale, PA.: Society of Automotive Engineers.
- Wicklund, R. A., & Gollwitzer, P. M. (1982). *Symbolic Self Completion*. Hillsdale, NJ: Lawrence Erlbaum.

- Wilde, G. L. S. (1982). The theory of risk homeostasis: Implications for safety and health. *Risk Analysis*, 2, 209-225.
- Willig, C. (2012). *Introducing Qualitative Interpretation and Analysis in Psychology*. Maidenhead, England: Open University Press.
- Wittenbrink, B. (2007). Measuring Attitudes through Priming. In B. Wittenbrink & N. Schwarz (Eds.), *Implicit Measures of Attitudes*. New York, NY: Guilford Press.
- Wittenbrink, B., & Schwarz, N. (2007). *Implicit Measures of Attitudes*. New York, NY: Guilford Press.
- Worldwatch Insitute (2007). *Biofuels for Transport: Global Potential and Implications for Sustainable Energy and Agriculture*. Camden, England: Earthscan.
- Yuille, A. L., & Bulthoff, H. H. (1996). Bayesian decision theory and psychophysics. In D. C. Knill & W. Richards (Eds.), *Perception as Bayesian Inference*. Cambridge, England. Cambridge University Press.
- Zadeh, L. A. (1965). Fuzzy Sets. *Information and Control*, 8 (3), 338-353.
- Zahavi, A., & Zahavi, A. (1997). *The handicap principle: a missing piece of Darwin's puzzle*. Oxford, England: Oxford University Press.
- Zickfeld, K., Eby, M., Matthews, H. D., & Weaver, A. J. (2009). Setting cumulative emissions targets to reduce the risk of dangerous climate change. *Proceedings of the National. Academy of Sciences*, 106, 16129–16134.
- Ziegler A. (2012). Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: A discrete choice analysis for Germany. *Transportation Research Part A: Policy and Practice*, 46, 1372-1385.
- Zikovitz, D. C., & Harris, L. R. (1999). Head tilt during driving. *Ergonomics*, 42(5), 740-746.

Zupan, L. H., Merfeld, D. M., & Darlot, C. (2002). Using sensory weighting to model the influence of canal, otolith and visual cues on spatial orientation and eye movements. *Biological Cybernetics*, 86(3), 209-230.

Zwicker, E. (1977). Procedure for calculating loudness of temporally variable sounds. *The Journal of the Acoustical Society of America*, 62(3), 675–682.

Zwicker, E., & Fastl, H. (1990). *Psychoacoustic Facts and Models*. Berlin, Germany: Springer-Verlag.